Chapter 1
INTRODUCTION

Background

The central island of a roundabout is generally characterized by a raised, circular area around which intersecting traffic circulates in a counter-clockwise direction allowing drivers to pass to the outlet leg of their choice. Landscaping elements within the central island are distinguishing features that provide an aesthetic advantage over traditional intersections. The most striking location for aesthetic treatments is at the focal point of the roundabout which is within the central island.

Currently, two schools of thought exist about the appropriate landscape elements which should be used within the central island.

Cross View Sight Line Blockage Over the Central Island

Some believe the central island not only provides a chance to create a visually appealing landscape but also allows the opportunity to block the drivers' view of vehicles along the portion of the roundabout opposing the entering approach. This sight line restriction allows the entering drivers' attention to be focused on:

- approaching vehicles from the left already in the roundabout's circulating traffic stream,
- making an entering right turn upon accepting a suitable gap, and
- maintaining a low speed once within the circulatory roadway.

An example of central-island landscaping with a completely blocked cross view is shown in FIGURE 1A.

Uninterrupted Cross View Sight Line Over the Central Island

Others suggest that the more visible all surrounding elements of the roundabout, the better able drivers should be able to negotiate its configuration, exit at the appropriate location, and view surrounding pedestrians and/or bicyclists in the process. An example of a clear central island cross view is shown in FIGURE 1B.

FIGURE 1A Example of Central Island Landscaping with Cross View Sight Line Blocked (Wilderness Ridge Drive and Wilderness Woods Place Intersection, Lincoln, NE)

FIGURE 1B Example of Central Island with Clear Sight Line Cross View (Sheridan Boulevard and 33rd Street Intersection, Lincoln, NE)

SIGHT LINE CROSS VIEW ISSUES

It is possible that safety and operational improvements could result from identifying whether reducing the drivers' sight distance across the center island improves or deteriorates operations at a roundabout. As yet, there has not been enough research to identify if and how central island landscaping elements may affect driver, pedestrian, and bicyclist safety and flow.

Stopping Sight Distance Issues

Stopping sight distance (SSD) is the distance along a roadway required for a driver to perceive and react to an object in the roadway interpreted as being hazardous and to brake to a complete stop before reaching that object (*1*). SSD should be provided at every point along the circulatory roadway and at all of the entering and exiting approaches (*1*). This distance should be measured along the vehicular path rather than as a straight line. FIGURE 2 shows a diagram of sight distance along the circulatory roadway of a single-lane roundabout.

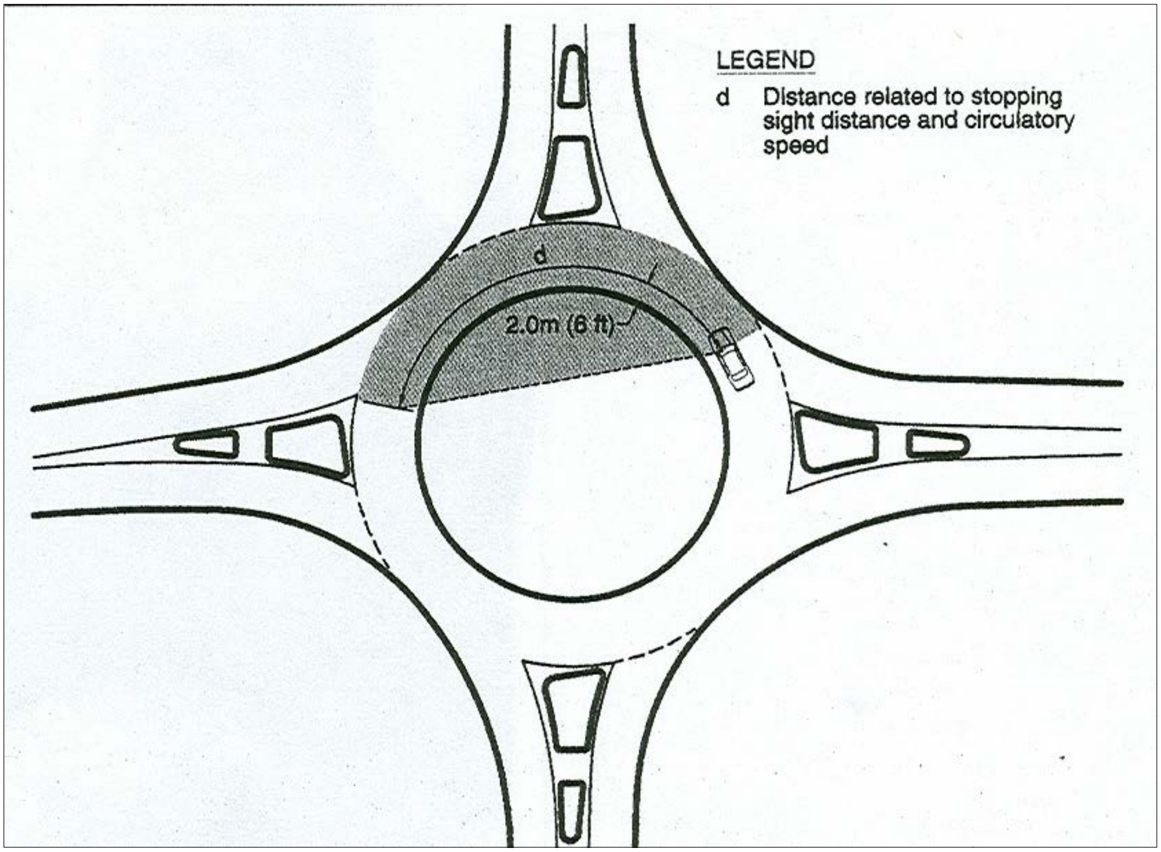


FIGURE 2 Sight Distance Along the Circulatory Roadway of a Single-Lane Roundabout (*1, page 160*)

Choice of central-island landscaping should be based on providing adequate stopping sight distance for the given design speed of the roundabout's circulatory roadway for the project's life. The required distance, d, necessary for appropriate stopping sight distance may be calculated by the following formula from the American Association of State and Highway Transportation Official's (AASHTO) roadway design guidebook, "A Policy on Geometric Design of Highways and Streets, 2004" often called the "Green Book" (*2*):

$$d = 1.47vt + 1.087\,(v^2/a) \qquad \textbf{EQUATION 1}$$

where:

d = stopping sight distance, ft,
v = initial speed, mph,
t = perception reaction time, assumed to be 2.5 seconds, and
a = driver deceleration, assumed to be 11.2 ft/s^2.

The vertical aspect of the sight line should use a 3.5 ft eye height for the driver of the vehicle on the circulatory roadway and 2.0 ft object height which represents the taillight height of a stopped vehicle on the circulatory roadway (*1*, *2*).

Intersection Sight Distance Issues

Intersection sight distance (ISD) is the distance required for a driver without the right-of-way to perceive and react to the presence of conflicting vehicles (*1*). These distances should be measured not as straight lines but as distances along the vehicular path. FIGURE 3 shows intersection sight distances along a single-lane roundabout.

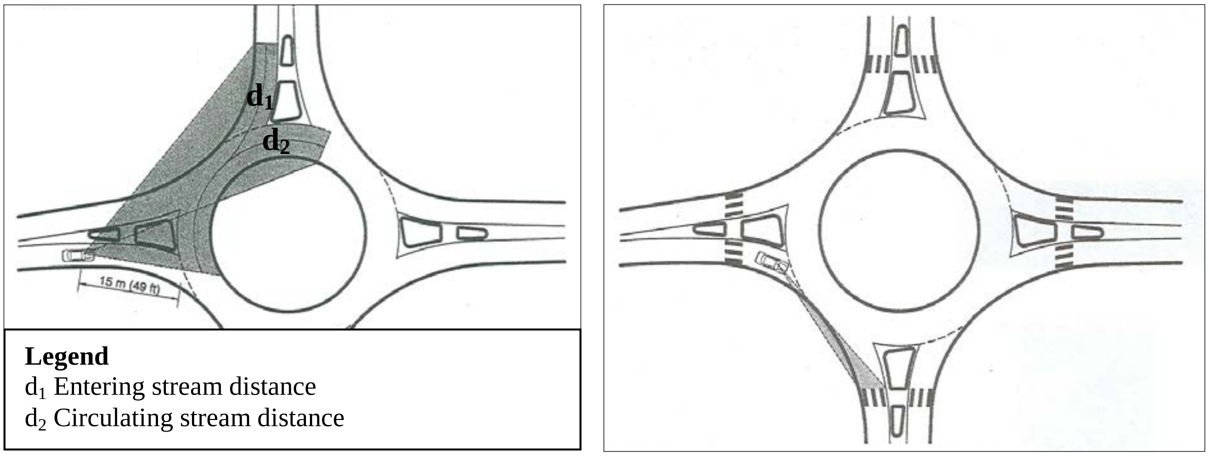


FIGURE 3 Intersection Sight Distance at a Single-Lane Roundabout (*1, pages 161, 162*)

British research suggests that the length of the approach sight distance leg should not be more than 49 ft based on findings that more accidents occur due to increased vehicular speeds related to drivers speeding up to enter the circulatory roadway before a vehicle on the adjacent approach to their immediate left enters (*1*).

The length of the conflicting leg of the sight triangle within the circulatory roadway, d_2, may be calculated using EQUATION 2 from the 2004 “Green Book”.

$$d_2 = 1.47 v_{major} t_c$$ **EQUATION 2**

where:

d_2 = length of conflicting leg of sight triangle, ft,
v_{major} = design speed of conflicting movement, mph, and
t_c = critical gap for entering the major road, seconds, equal to 6.5 seconds.

The conflicting traffic stream related to cross view sight distance is comprised of vehicles that entered the roundabout prior to the immediate upstream entry. The speed of vehicles can be approximated by taking the speed of left-turning vehicles traversing a radius equal to the radius of the outer edge of the central island (or truck apron, if present) plus 6 additional ft (see FIGURES 2 and 3). According to the “Green Book”, the critical gap, t_c, for entering the major road is based on the time necessary for a driver to turn right while slowing the conflicting traffic no less than 70 percent of its initial speed. This is based on the study of critical gaps at stop-controlled intersections, adjusted for yield-controlled conditions (*3*). The critical gap value of 6.5 seconds is based on passenger cars, assumed to be the most critical design vehicle for ISD. Single-unit and combination trucks speeds are 6 mph and 9-12 mph slower than passenger cars, respectively.

The three-dimensional characteristics of any choice of central-island landscaping should allow uninterrupted intersection sight distance from all approaches based on the design speed of the roundabout. Consideration should also be given to future maintenance requirements (maturing plantings) ensuring adequate ISD for the life of the project.

The FHWA document, “Roundabouts: An Informational Guide” (1) recommends providing no more than the minimum required ISD on each approach, stating that excessive intersection sight distance can lead to higher vehicle speeds that reduce the safety of the intersection for all road users. The document doesn’t include a reference to specific evidence related to the central island cross view issue.

“Forgiving” Roadside Landscape Issues

Although relatively rare, some central island crashes occur due to loss of vehicle control at the entry to the circulatory roadway. Therefore, it is important to follow guidelines suggested by the AASHTO Roadside Design Guide to provide as forgiving a roadside as possible (*4*). The slope of the central island should not exceed a slope of 1 ft vertically in 6 ft horizontally. FIGURE 4 shows a representative cross-sectional view of this concept.

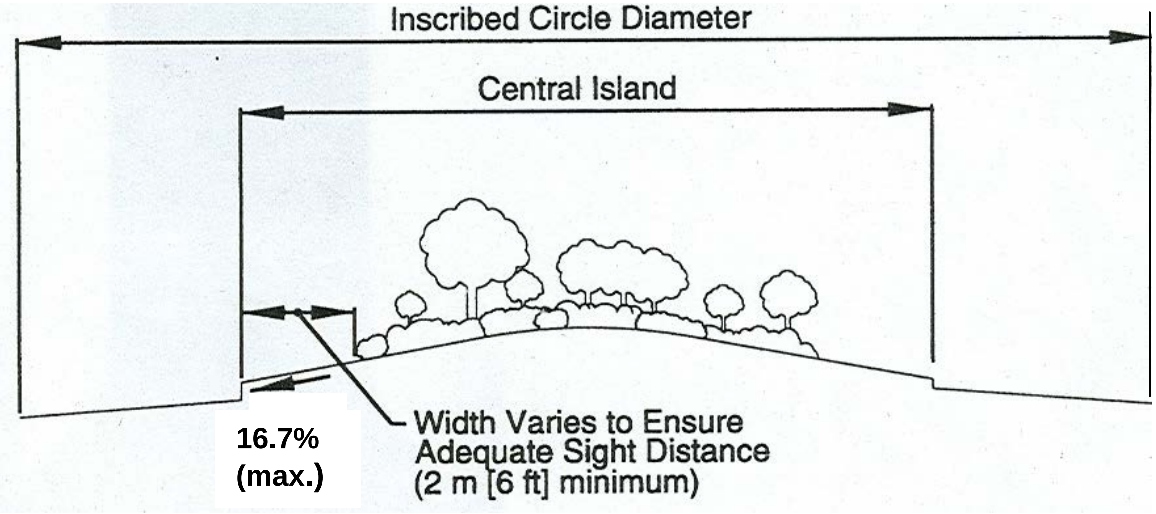


FIGURE 4 Assuring a Forgiving Roadside for Possible Errant Vehicle Entry Within the Limits of the Central Island (*1, page 208*)

OBJECTIVE

The overall objective of the research project was to study the safety and operational effects that three-dimensional elements within the central island of a single-lane roundabout have upon driver, pedestrian and bicyclist behaviors and their interactions.

METHODOLOGY

Behaviors of drivers, pedestrians and bicyclists were studied in a “before” landscaping situation where the central island of a single-lane roundabout was covered only in grass and an “after” landscaping condition when the central island contained three 7 ft high by 5 ft diameter evergreen trees. Once data was collected under both conditions, operational measures of effectiveness were used to evaluate safety and operations in both conditions.

To find the effects of the change in cross view blockage in the “before” and “after” periods, the following measures of effectiveness were used to evaluate driver behaviors:

- **Speed Data:** Free flow vehicle speeds at locations 10 ft and 150 ft from the approach side of the crosswalk (8 locations) and at four locations within the circulatory roadway,
- **Capacity Data:** Critical gap (the minimum time interval in the circulatory traffic stream that allows entry for one approach vehicle), and
- **Capacity Data:** Follow-up time (the time between the departure of one vehicle from an approach and departure of the next vehicle using the same circulatory gap, under a condition of continuous queuing on the approach).

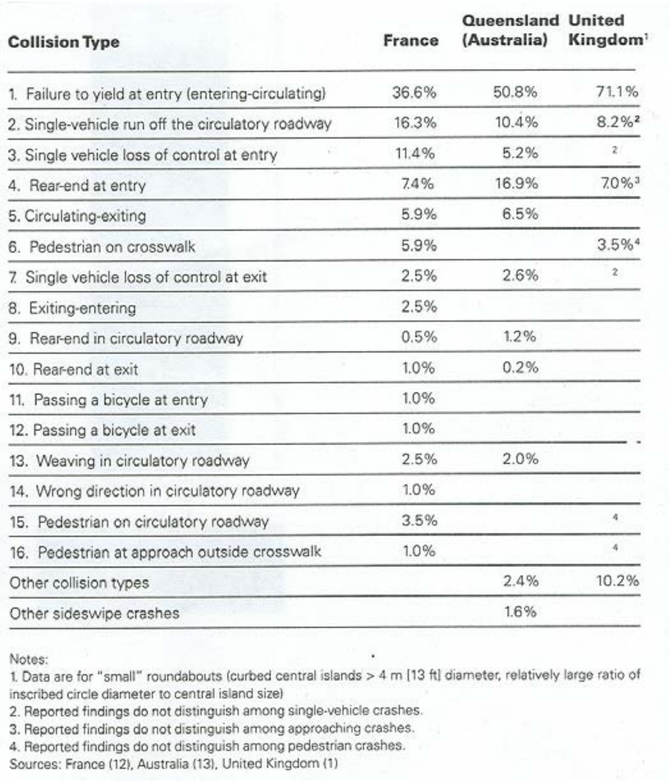
Pedestrian and bicyclist behaviors were studied using direct observation and viewing of videotape recordings.

Chapter 2
LITERATURE REVIEW

A search of existing research related to the benefits or detriments of various types of central-island landscaping treatments resulting in the partial or total blockage of the drivers' cross view produced no findings that this specific subject had ever been studied with respect to operations. Safety and operational issues that may relate to cross view sight distance from previous research documents were reviewed to define parameters that may be affected by cross view sight distance.

Relationship Between Central Island Landscaping Elements and Safety

FIGURE 5 shows a graphical depiction of sixteen of the most common types of collisions experienced at roundabouts and a summary of the percentage of those crashes according to statistics available from France, Australia, and the United Kingdom. Although it is possible that the available sight distance across the central island may have some impact on many of these collision types, Types 1, 2, 3, 5, 7, 9, 12, and 15 can be identified as having a logical impact. Summing the percentage of these types of collisions results in 78% of the total identified in France, 77% of the total from Australia, and 79% of the United Kingdom total. Types 1, 3, 9, 12, and 15 are viewed as the most likely to be affected by central-island landscaping in some fashion. The percentage sum of these collisions is 53%, 57%, and 71% from the French, Australian, and UK accident data respectively.



Collision Type	France	Queensland (Australia)	United Kingdom[1]
1. Failure to yield at entry (entering-circulating)	36.6%	50.8%	71.1%
2. Single-vehicle run off the circulatory roadway	16.3%	10.4%	8.2%[2]
3. Single vehicle loss of control at entry	11.4%	5.2%	[2]
4. Rear-end at entry	7.4%	16.9%	7.0%[3]
5. Circulating-exiting	5.9%	6.5%	
6. Pedestrian on crosswalk	5.9%		3.5%[4]
7. Single vehicle loss of control at exit	2.5%	2.6%	[2]
8. Exiting-entering	2.5%		
9. Rear-end in circulatory roadway	0.5%	1.2%	
10. Rear-end at exit	1.0%	0.2%	
11. Passing a bicycle at entry	1.0%		
12. Passing a bicycle at exit	1.0%		
13. Weaving in circulatory roadway	2.5%	2.0%	
14. Wrong direction in circulatory roadway	1.0%		
15. Pedestrian on circulatory roadway	3.5%		[4]
16. Pedestrian at approach outside crosswalk	1.0%		[4]
Other collision types		2.4%	10.2%
Other sideswipe crashes		1.6%	

Notes:
1. Data are for "small" roundabouts (curbed central islands > 4 m [13 ft] diameter, relatively large ratio of inscribed circle diameter to central island size)
2. Reported findings do not distinguish among single-vehicle crashes.
3. Reported findings do not distinguish among approaching crashes.
4. Reported findings do not distinguish among pedestrian crashes.
Sources: France (12), Australia (13), United Kingdom (1)

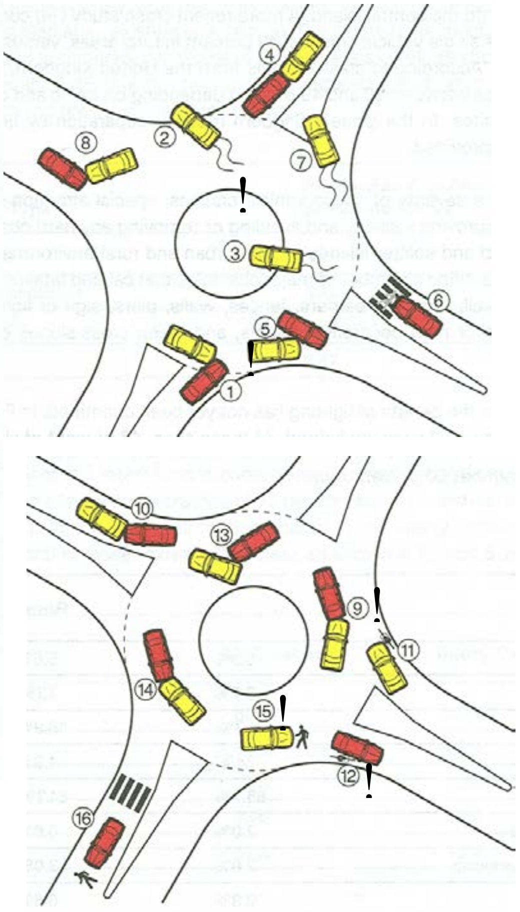


FIGURE 5 Comparison of Collision Types at Roundabouts (*1, pp. 114, 115*)

A French study (5) identified the following obstacles causing fatalities and injuries involving single vehicles within the central and splitter islands:

- Trees,
- Guardrail,
- Concrete barriers,
- Fences,
- Walls,
- Piers,
- Sign or light poles,
- Landscaping pots or hard decorative objects, and
- Steep cross slopes.

This research project studied the behaviors and the interactions of vehicles, pedestrians, and bicyclists to evaluate how cross view sight line blockage may affect the safety of all users.

Relationship Between Central Island Landscaping Elements and Traffic Operations

Based on the 2000 Highway Capacity Manual (HCM 2000) (*5*), the capacity of a roundabout can be estimated using gap acceptance techniques with the parameters of critical gap and follow-up time. Critical gap, t_c, is defined as the minimum time interval in the major-street traffic stream (circulatory roadway) that allows intersection entry for one minor-street vehicle (vehicle on the approach). Gaps less than the critical gap would by rejected be the driver and gaps greater than or equal to the critical gap would be accepted by the driver (*5*). Follow-up time, t_f, is defined as the time between the departure of one vehicle from one of the roundabout approaches and the departure of the next vehicle using the same major-street gap, under a condition of continuous queuing on the approach. According to the HCM 2000 capacity analysis method, roundabout capacity depends on the conflicting circulating flow and the roundabout geometry.

In a single-lane roundabout, circulating flow should never exceed 1,800 vph at any point (*5*). Exit flows that exceed 1,200 vph may indicate the need to add one more lane at the exit approach (*5*). As at other forms of unsignalized intersections, when traffic flows on an approach exceed about 85 percent of potential capacity, delays and queue lengths vary significantly about their mean values. Therefore, it is recommended that roundabouts be designed to operate at no more than 85 percent of their estimated capacity.

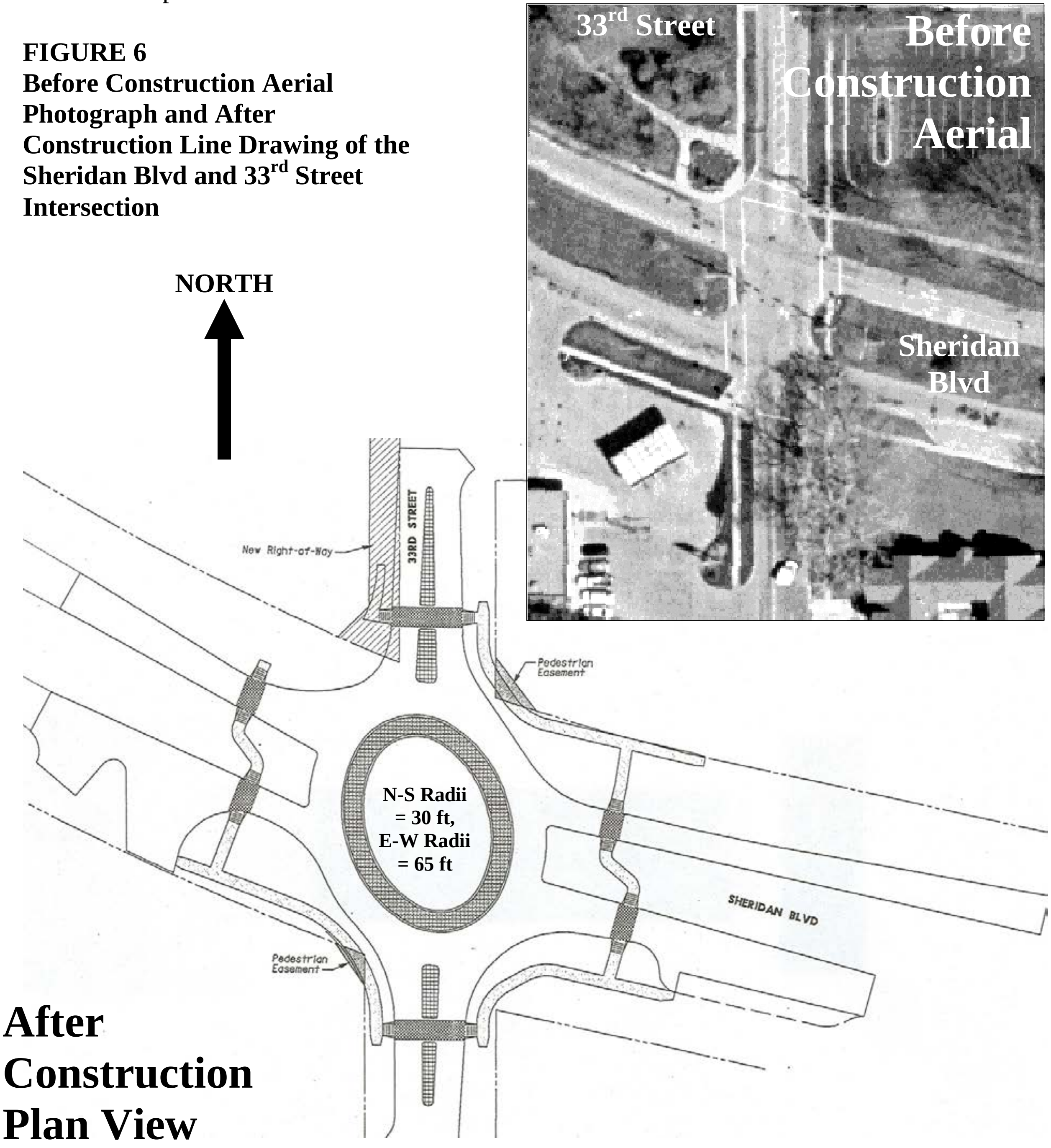
This research project studied the critical gap and follow-up time of drivers in the “before” and “after” conditions of central-island landscaping elements to evaluate changes in driver behavior that may be related to cross view sight distance and how they relate to traffic operations within the intersection.

Chapter 3
AN OPPORTUNITY FOR STUDY OF CROSS VIEW SIGHT DISTANCE BLOCKAGE

An Opportune Study Site

Nebraska is one of many states within US boundaries that have recognized the modern roundabout as an optimal intersection design choice for specific situations. The first such application for an arterial route in the state occurred at the intersection of Sheridan Boulevard and 33rd Street in Lincoln, NE in 2002. FIGURE 6 shows before and after construction plan views of the intersection.

FIGURE 6
Before Construction Aerial Photograph and After Construction Line Drawing of the Sheridan Blvd and 33rd Street Intersection



The unusual oval shape of the roundabout resulted from the effort to perpetuate the wide turf median along Sheridan Blvd, an aesthetic characteristic thought to be an important feature of the "boulevard look" of the urban arterial. The skew of the oval was introduced to provide the characteristic horizontal jog at the north and south approach entry point at 33rd Street to significantly slow the speeds of drivers.

The traditional 4-legged signalized intersection at this location was reconstructed in the year 2002 to a roundabout to reduce crashes that were prevalent primarily due to the wide median of Sheridan Blvd which resulted in awkward left-turning movements due to misinterpretation of traffic signals. Intersection traffic volumes collected in the year 2000 totaled 16,950 entering vehicles per day. The distribution of approach volumes in 2000 were as follows:

- East approach (Sheridan Blvd): 3,850 vehicles per day,
- West approach (Sheridan Blvd): 5,300 vehicles per day,
- North approach (33rd Street): 3,250 vehicles per day, and
- South approach (33rd Street): 4,550 vehicles per day.

The opportunity to collect pertinent data from a "before" landscaping condition with grass central-island landscaping and the "after" landscaping treatment of three strategically-spaced Black Hills spruce trees presented itself. The tree species was selected to match that of existing evergreens along the wide median of Sheridan Blvd and the placement of the trees (when mature) was intended to totally block the entering drivers' view across the central island. FIGURE 7 shows the "before" and "after" condition from the viewpoint of the west approach of Sheridan Blvd looking east, 10 ft in advance of the pedestrian crossing.

FIGURE 7 Before and After Views of Central Island from West Approach on Sheridan Blvd, 10 ft in Advance of Pedestrian Crossing

FIGURE 8 shows a line drawing plan view of the cross view sight blockage of drivers at entry points along the roundabout at the time of spruce tree planting (7 ft high by 5 ft in diameter) and at the time of tree maturity.

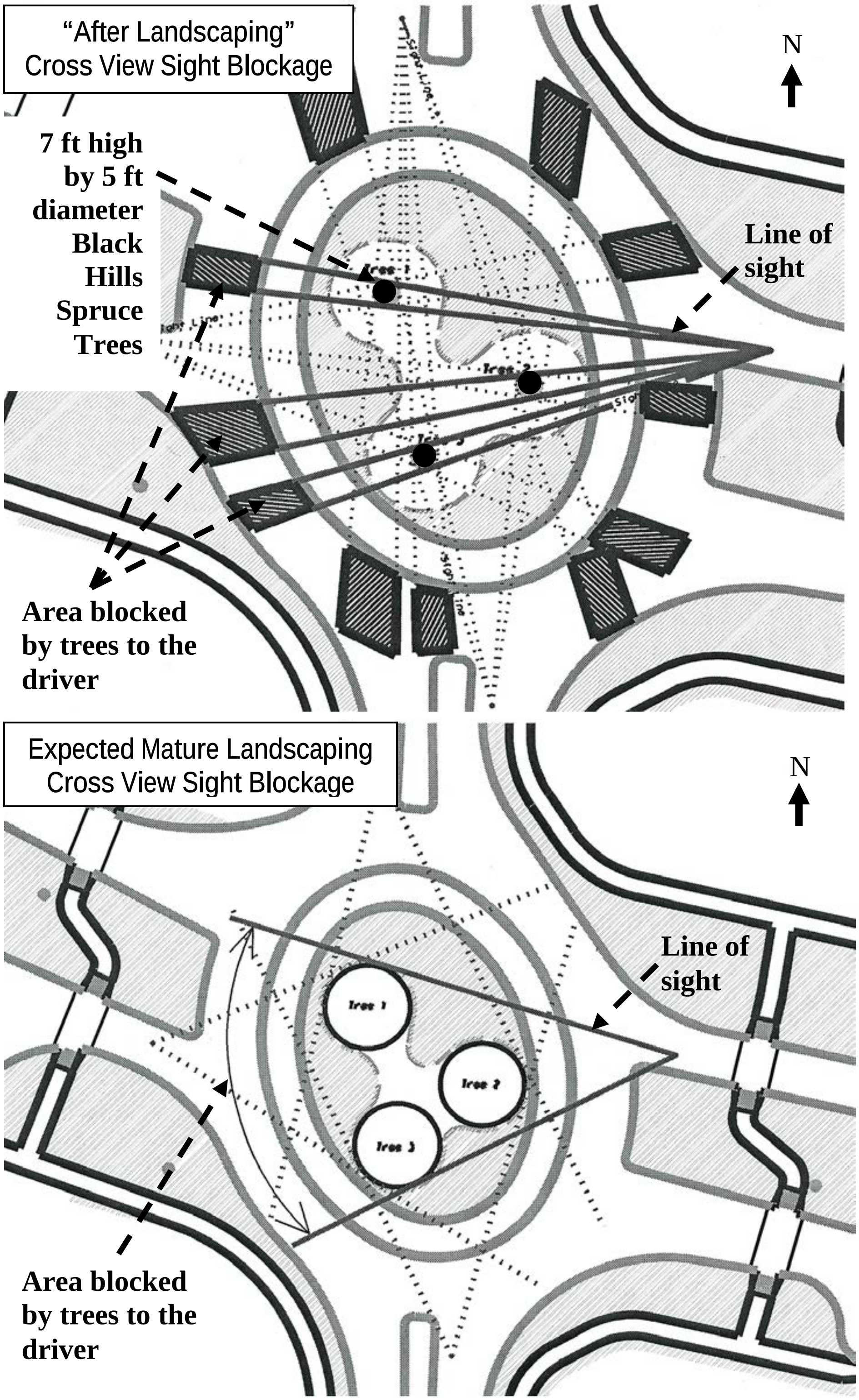


FIGURE 8 Approach Drivers' View Blocked by Black Hill Spruce Trees in "After" Landscaping and Expected Mature Landscaping Conditions

Chapter 4
STUDY DESIGN AND DATA COLLECTION METHODOLOGY

Study Design Methodology

To find the effects of the change in cross view blockage in the "before" and "after" periods, the following measures of effectiveness were used to evaluate driver behaviors:

- **Speed Data:** Free flow vehicle speeds at locations 10 ft and 150 ft from the approach side of the crosswalk (8 locations) and at 4 locations within the circulatory roadway,
- **Capacity Data:** Critical gap (the minimum time interval in the circulatory traffic stream that allows entry for one approach vehicle), and
- **Capacity Data:** Follow-up time (the time between the departure of one vehicle from an approach and departure of the next vehicle using the same circulatory gap, under a condition of continuous queuing on the approach).

Data Collection for Speed Data

The roundabout under study was opened to traffic on June 26, 2002. The "before" landscaping speed data was collected in late September and early October of 2002. The three-month period between the opening of the roundabout and the beginning of "before" data collection allowed the traveling public to become accustomed to the new design of the intersection. The "before" data was collected as close to the installation date of the spruce trees as possible. The "after" landscaping data was collected between March and July of 2003.

"Before" and "after" speeds were collected using a single research assistant with a Light Detection and Ranging (Lidar) instrument. The Lidar "gun" measured the speed of vehicles by transmitting light to the moving vehicle, which was then reflected back to the instrument and displayed digitally in units of miles per hour. The data collector positioned himself to be concealed from drivers as they approached the intersection, therefore speed values collected from the Lidar gun had to be adjusted for the collector's angle of view since some of his positions were not on the direct trajectory of the vehicles.

Speeds were gathered in daylight hours on weekdays during non-peak time periods so free flow speed data (drivers uninfluenced by behaviors of other vehicles in close proximity) could be collected.

Locations of Data Collection Points for Speed Data

There were a total of 12 locations where speed data were collected. Eight of these positions were at 10 ft and 150 ft in advance of the near side of the crosswalk on each approach and four positions were within the circulatory roadway at locations adjacent to the splitter islands. The crosswalks on all approaches were located 25 ft from the yield line at the circulatory roadway. Figure 9 shows a plan view drawing of the twelve locations under study.

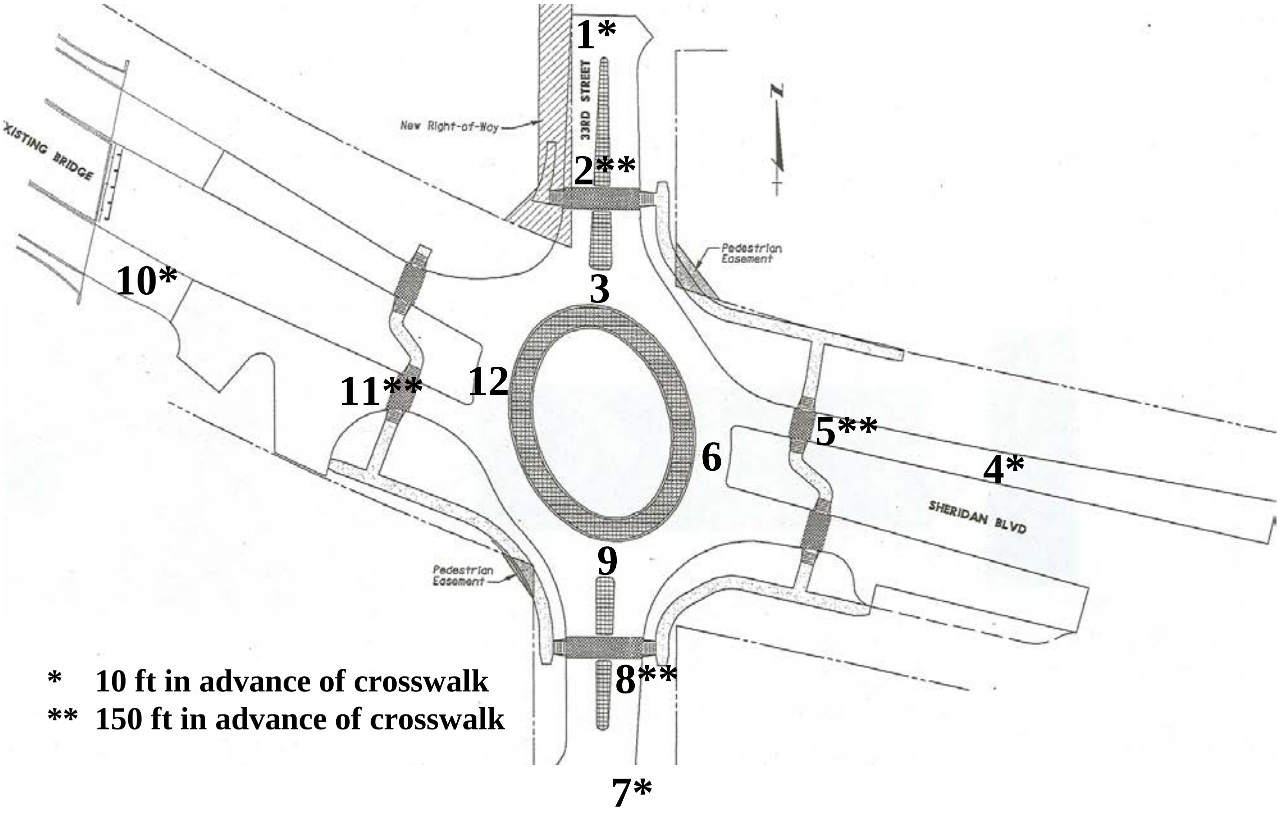


FIGURE 9 Positions of Speed Data Collection Points at Sheridan Blvd and 33rd Street Intersection

Speed Data Sample Sizes and Error

At each of the 12 data collection points, approximately 250 speed samples were recorded in the "before" and "after" periods. This sample size was estimated to ensure reasonable accuracy of the statistical parameters to be calculated from the data. EQUATION 3 (*7*) was used to calculate the required sample size based on different estimated errors for the 95th-percentile speed.

$$N = \frac{S^2K^2(2 + U^2)}{2E^2}$$ **EQUATION 3**

where,

N = minimum number of measured speeds,
S = estimated sample standard deviation (± 5.3 mph used for an initial estimate),
K = constant from the standard normal distribution corresponding to a certain confidence level (1.96 for 95 percent confidence),
E = permitted error in the average speed estimation (1 mph), and
U = constant corresponding to 95th-percentile speed (1.64).

Based on these variables, the minimum number of measured speeds needed to be 95 percent confident in obtaining 95th-percentile speeds was approximately 250 samples. After collecting all of the data for this project, the standard deviations along all twelve speed data collection points were calculated and were found to range from 2.5 mph to 4 mph, on average. Using the field-derived standard deviation of 4 mph (worst case scenario), the sample size of 250 was checked for appropriateness. A minimum sample size of 576 was required for an estimated error of ±0.5 mph and a minimum sample size of 144 was necessary for an estimated error of ±1.0 mph. Therefore, using about 250 samples would yield accuracy about midway between 0.5 and 1.0 mph.

Due to the necessity of getting all the "before" data collected before the spruce trees were planted, some data was collected when the pavement was moist after rain showers had occurred. It was important to test the moist-pavement speeds to see if they were significantly different from the dry-pavement speeds. If the speeds collected under moist pavement conditions were found to be significantly different at the 95 percent confidence level, only dry pavement speeds were used for further analysis. TABLE 1 summarizes the final sample sizes used for evaluation purposes in both "before" and "after" conditions.

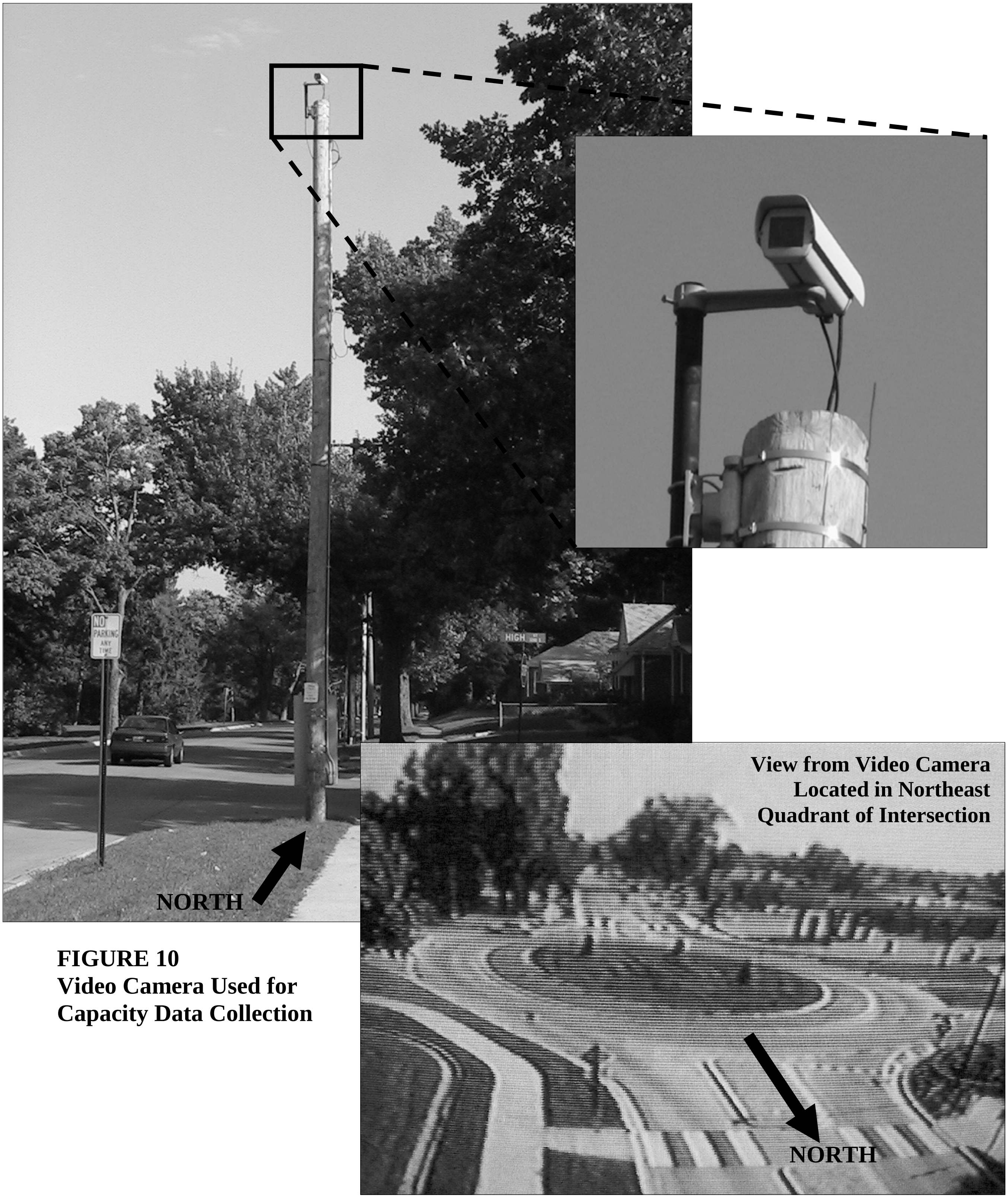
TABLE 1. Final Speed Sample Sizes After Significantly Different Moist-Pavement Samples Removed

Speed Data Collection Point	Speed Data Collection Point Number	"Before" Period Sample Size	"After" Period Sample Size
North Approach, 150 ft	1	235	255
North Approach, 10 ft	2	217	255
North Splitter	3	253	255
East Approach, 150 ft	4	253	255
East Approach, 10 ft	5	166	255
East Splitter	6	195	255
South Approach, 150 ft	7	255	255
South Approach, 10 ft	8	128	210
South Splitter	9	260	255
West Approach, 150 ft	10	163	255
West Approach, 10 ft	11	198	255
West Splitter	12	252	255

Data Collection For Capacity Data

In order to collect information about the critical gap and follow-up time exhibited by drivers in the "before" and "after" periods, it was necessary to videotape behavior so a stopwatch could be used to determine the field study time spans.

The City of Lincoln Public Works and Utilities Department installed a temporary pole with a video camera 60 ft north of the circulatory roadway in the northeast quadrant of the intersection. FIGURE 10 shows the camera location and its view of the roundabout.



View from Video Camera Located in Northeast Quadrant of Intersection

FIGURE 10
Video Camera Used for Capacity Data Collection

Capacity Data Sample Sizes and Error

The parameters of critical gap and follow-up time of vehicular traffic at the study site were determined by a research assistant observing videotapes of the operations at the roundabout using a stopwatch to find the critical gaps and follow-up times between vehicles. The same techniques were used to collect all the data from both the "before" and "after" periods. EQUATION 3 was used again to determine the appropriate sample sizes to collect from the video so results could be of similar accuracy to the speed data already collected. TABLE 2 summarizes the variables used in EQUATION 3 as well as the minimum sample sizes needed for the critical gap and follow-up time. The critical gap times collected were the largest rejected and the smallest accepted gaps possible.

TABLE 2. Minimum Sample Sizes for Critical Gap (t_c) and Follow-Up Time (t_f)

Variables in EQUATION 3	**Critical Gap, t_c**	**Follow-Up Time, T_f**
S (seconds)	1.2*	0.5*
K	1.96	1.96
U	1.64	1.64
E (seconds)	0.25	0.15
N, Minimum Sample Size	**208**	**100**

***Worst case scenario values from data collected.**

Determination of Circulating Traffic Flows and Approach Capacity

To calculate the capacity at approaches of roundabouts, the entering and exiting location of each vehicle path must be determined. These paths must be converted to circulating flows. FIGURE 11 shows a representation of how the circulating flows are determined at each of the four approaches at a single-lane roundabout.

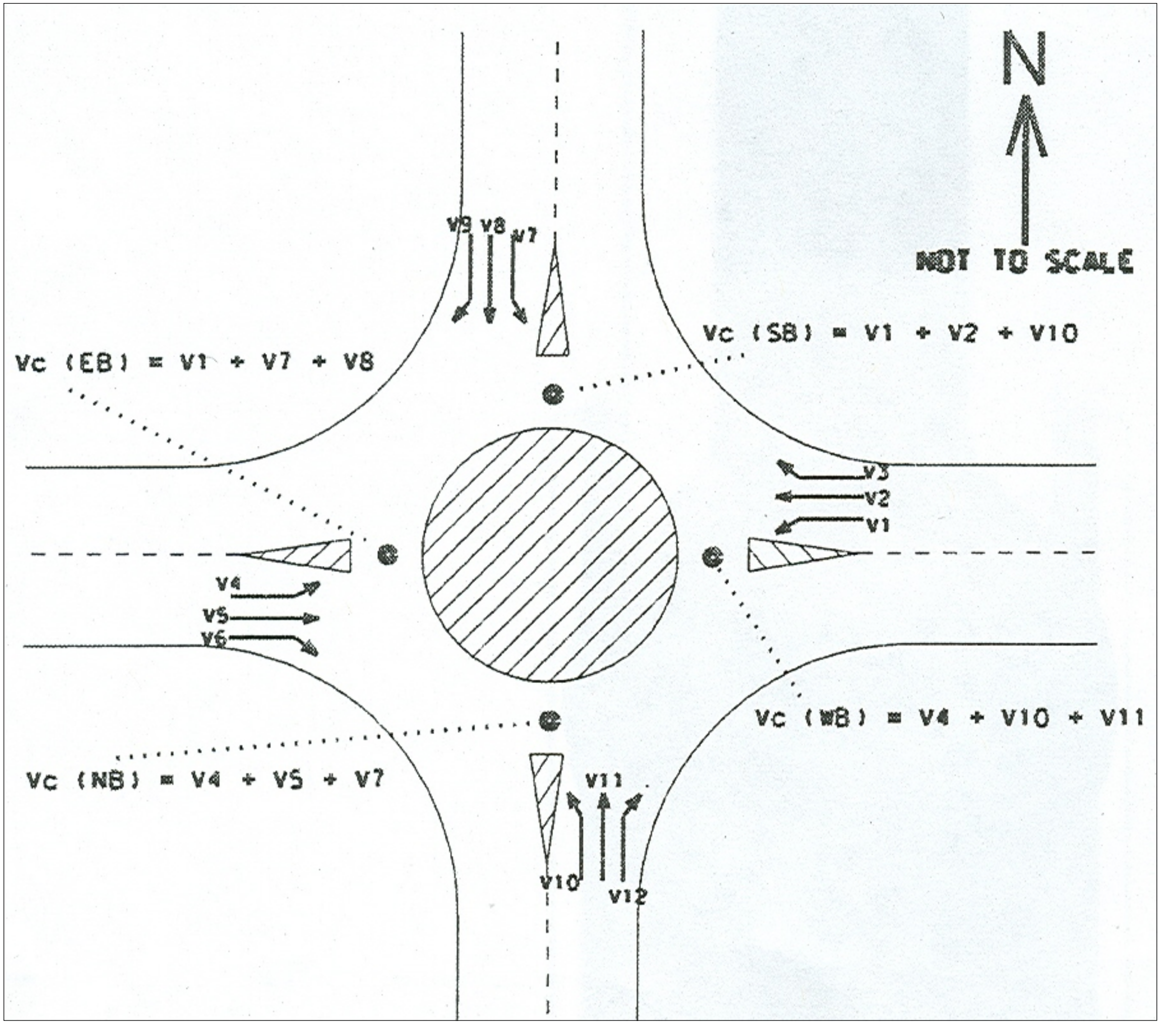


FIGURE 11 Determination of Circulatory Flows at a Single-Lane Roundabout

For example, from FIGURE 11 the circulating flow at the northbound approach (v_{cNB}) is determined by summing the streams of traffic volumes v_4, v_5, and v_7 which will be conflicting with the entering northbound approach vehicle and essentially governing its capacity. Circulating flows may be established for the other approaches in a similar manner. Good estimates of capacity have been found for single-lane roundabouts if the circulating flows are random (*6*). FIGURE 12 shows a map of the proximity of traffic signals within the study area. Since the closest signal is about 0.5 miles away from the intersection, flows were assumed to be random rather than in platoons.

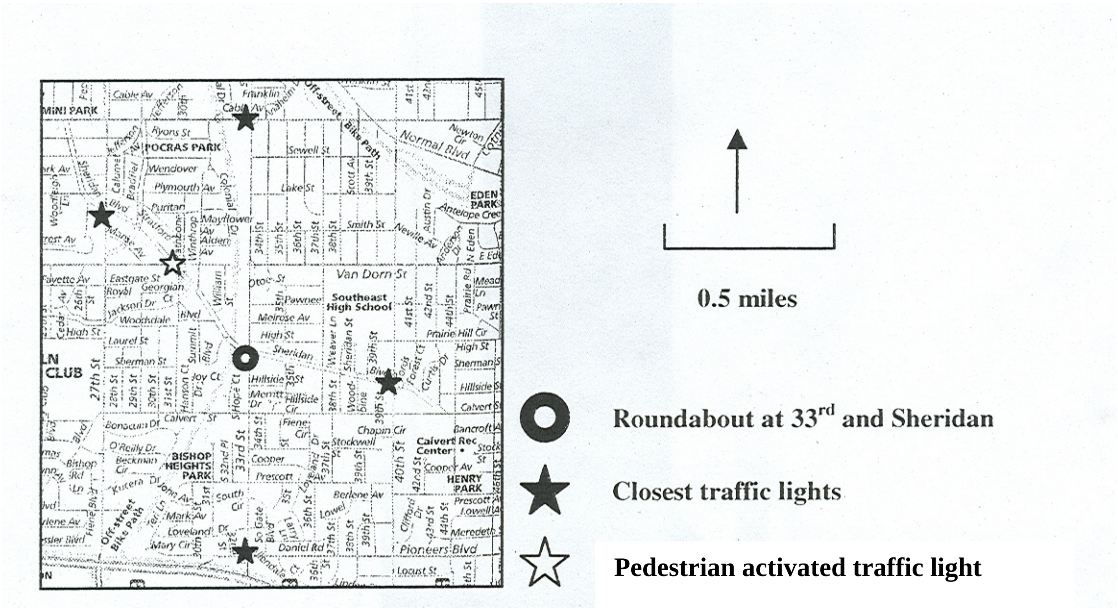


FIGURE 12 Map of Proximity of Traffic Signals to Study Site

Once the circulating flows, critical gap and follow-up time ranges are determined, approach capacity can be calculated using the EQUATION 4 shown below.

$$c_a = \frac{v_c\, e^{-vctc/3600}}{1 - e^{-vctc/3600}}$$

EQUATION 4

where:

c_a = approach capacity, vph,
v_c = conflicting circulating traffic, vph,
t_c = critical gap, seconds, and
t_f = follow-up time, seconds.

It is important to note that the HCM 2000 method should be used only when circulating traffic flows at each approach do not exceed 1200 vph.

Videotapes from the “before” and “after” periods were reviewed to determine the peak-hour traffic period which was observed to be between 4:45 and 5:45 pm in both conditions. Traffic volumes were counted from both periods on three different days then averaged to determine an estimate of the peak-hour volume at the study site. TABLE 3 shows that the circulating volumes on all approaches in both time periods were under the 1200 vph limit defined in the HCM 2000 capacity method.

TABLE 3 Circulating Flows at the Sheridan Blvd and 33rd Street Roundabout in the "Before" and "After" Periods

Approach Direction	Circulating Flow, v_c (vph)	
	"Before" Period	**"After" Period**
West Approach	316	186
East Approach	357	396
North Approach	335	443
South Approach	494	534

Collection of Pedestrian and Bicyclist Behavior

Observations of pedestrian and bicyclist road user activity were collected by viewing videotapes during daylight hours at the study site. Results of the behavior data are shown and evaluated in the following chapter.

Chapter 5
RESULTS OF DATA ANALYSIS

Vehicle Speed Data Analysis Results

TABLES 4 and 5 summarize the speed statistic results of the “before” and “after” speed study in detail. Seven of the 12 study points resulted in a significantly lower mean speed and standard deviation at the 95 percent confidence level. Those locations with less than significant differences were very close in magnitude in both “before” and “after” conditions. The 95th- and 85th-percentile speeds at all 12 locations were lower in the “after” condition than the “before” condition as shown in TABLE 5. FIGURES 13 through 16 show the results in graphical form.

TABLE 4. “Before” and “After” Speed Statistic Study Results for Means and Standard Deviations

▨ **Indicates “After” case is significantly lower than “Before” case at the 95 percent confidence level.**

150 Ft from Pedestrian Crossing

Point	Period	Mean, mph	Std Dev, mph	Sample Size
1	Before	31.5	3.6	235
1	After	30.5	3.0	255
4	Before	29.4	4.6	253
4	After	29.6	3.6	255
7	Before	29.2	3.1	255
7	After	29.4	3.2	255
12	Before	30.4	3.8	252
12	After	29.4	3.1	255

10 Ft from Pedestrian Crossing

Point	Period	Mean, mph	Std Dev, mph	Sample Size
2	Before	23.6	3.4	217
2	After	21.9	2.8	255
5	Before	20.5	3.1	166
5	After	19.5	2.8	255
8	Before	21.1	3.5	128
8	After	19.2	3.3	210
11	Before	20.7	3.1	198
11	After	20.2	2.7	255

Approaching Tight Radius

Point	Period	Mean, mph	Std Dev, mph	Sample Size
3	Before	12.3	2.6	253
3	After	11.8	2.0	255
9	Before	12.6	2.0	260
9	After	12.7	1.8	255

Approaching Flat Radius

Point	Period	Mean, mph	Std Dev, mph	Sample Size
6	Before	14.0	2.6	195
6	After	13.9	2.4	258
10	Before	14.8	3.3	163
10	After	14.1	3.2	255

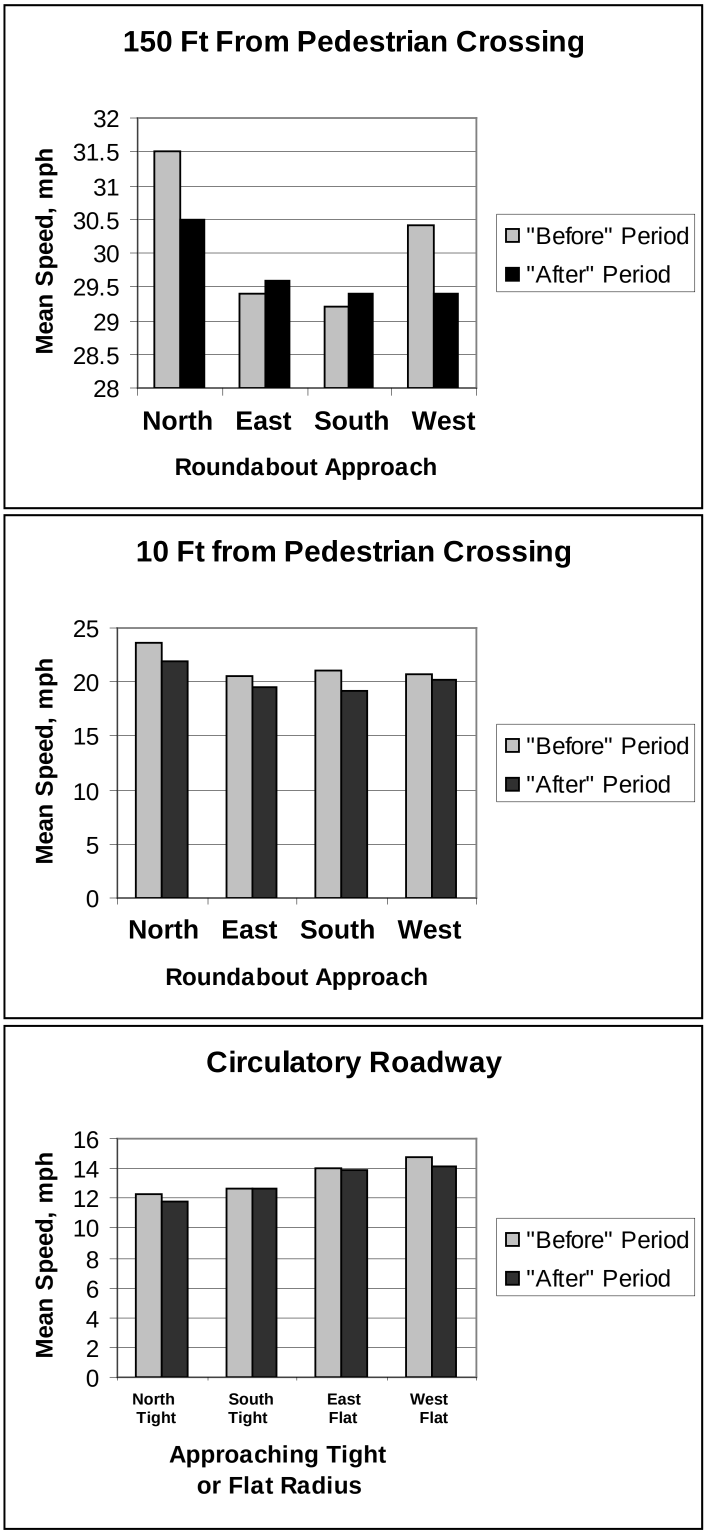


FIGURE 13 Graphical View of Difference in "Before" and "After" Period Mean Speeds, mph

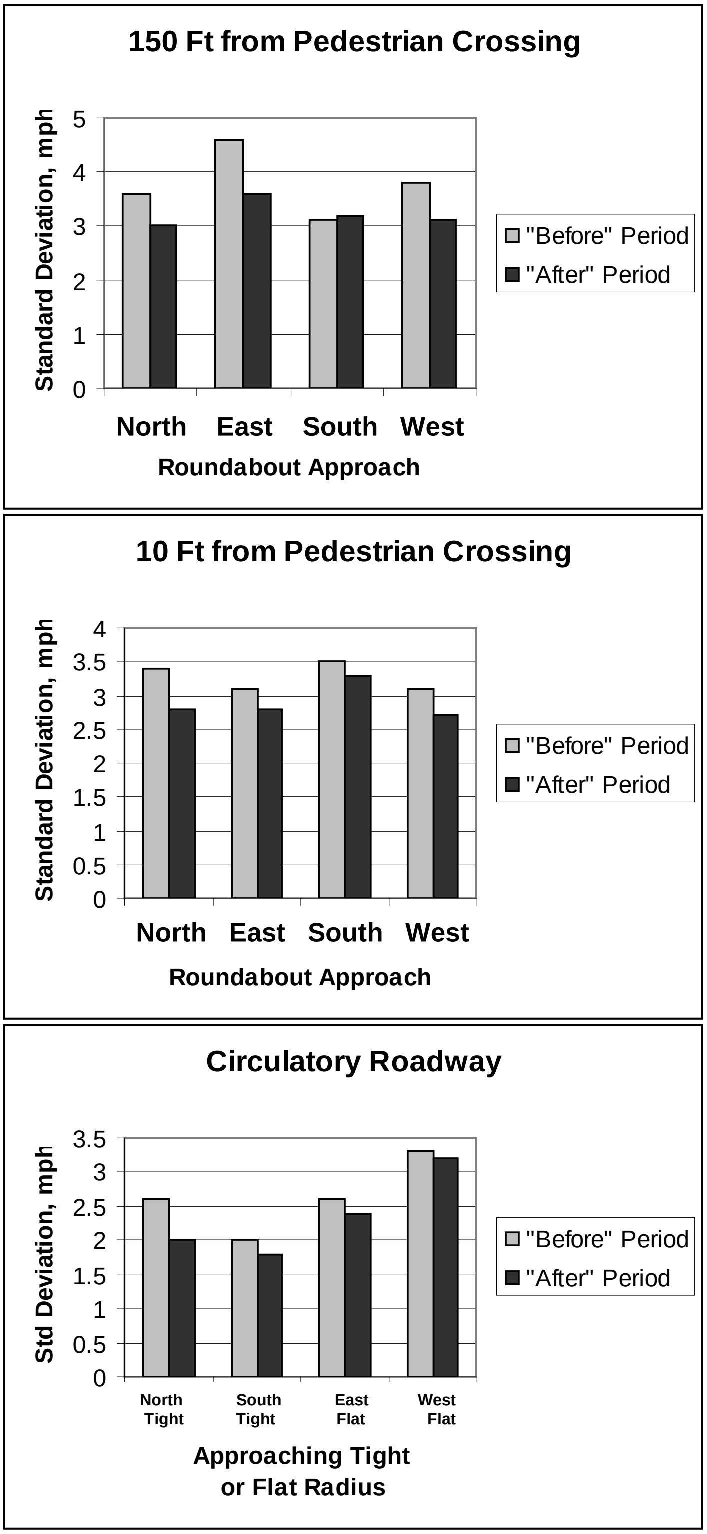
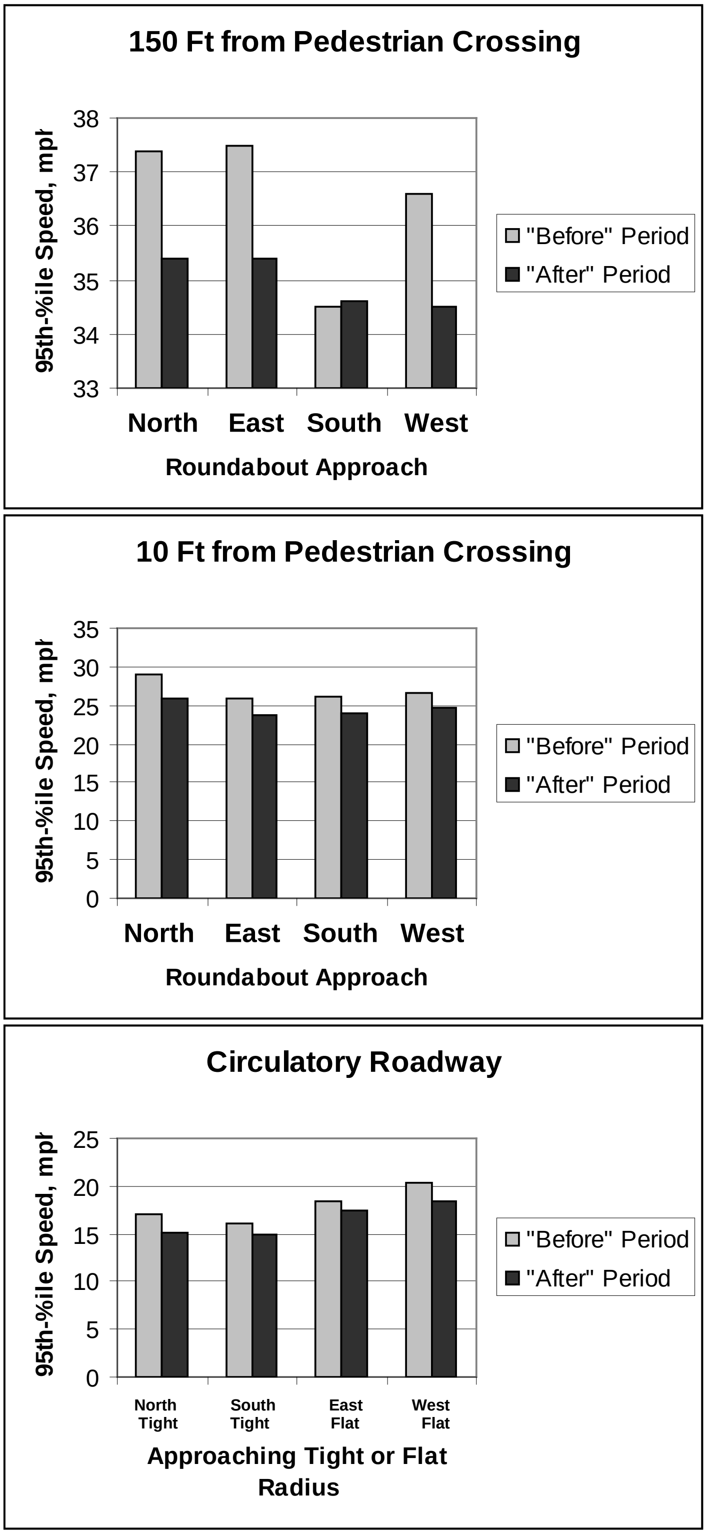


FIGURE 14 Graphical View of Difference in "Before" and "After" Period Standard Deviations, mph

TABLE 5 “Before” and “After” Speed Statistic Study Results for Percentile Speeds

150 Ft from Pedestrian Crossing				
Point	**Period**	**95th-Percentile Speed, mph**	**85th-Percentile Speed, mph**	**Sample Size**
1	Before	37.4	35.4	235
1	After	35.4	33.4	255
4	Before	37.5	33.2	253
4	After	35.4	33.2	255
7	Before	34.6	32.6	255
7	After	34.6	32.6	255
12	Before	36.6	34.5	252
12	After	34.5	32.5	255
10 Ft from Pedestrian Crossing				
Point	**Period**	**95th-Percentile Speed, mph**	**85th-Percentile Speed, mph**	**Sample Size**
2	Before	28.9	26.8	217
2	After	25.8	24.7	255
5	Before	26.0	23.8	166
5	After	23.8	21.6	255
8	Before	26.1	25.1	128
8	After	24.0	23.0	210
11	Before	26.6	23.4	198
11	After	24.7	23.4	255
Approaching Tight Radius				
Point	**Period**	**95th-Percentile Speed, mph**	**85th-Percentile Speed, mph**	**Sample Size**
3	Before	17.1	15.1	253
3	After	15.1	14.1	255
9	Before	16.0	14.0	260
9	After	15.0	14.0	255
Approaching Flat Radius				
Point	**Period**	**95th-Percentile Speed, mph**	**85th-Percentile Speed, mph**	**Sample Size**
6	Before	18.4	16.4	195
6	After	17.5	16.4	258
10	Before	20.3	18.4	163
10	After	18.4	16.6	255


150 Ft from Pedestrian Crossing

10 Ft from Pedestrian Crossing

Circulatory Roadway

FIGURE 15 Graphical View of Difference in "Before" and "After" Period 95th-Percentile Speeds, mph

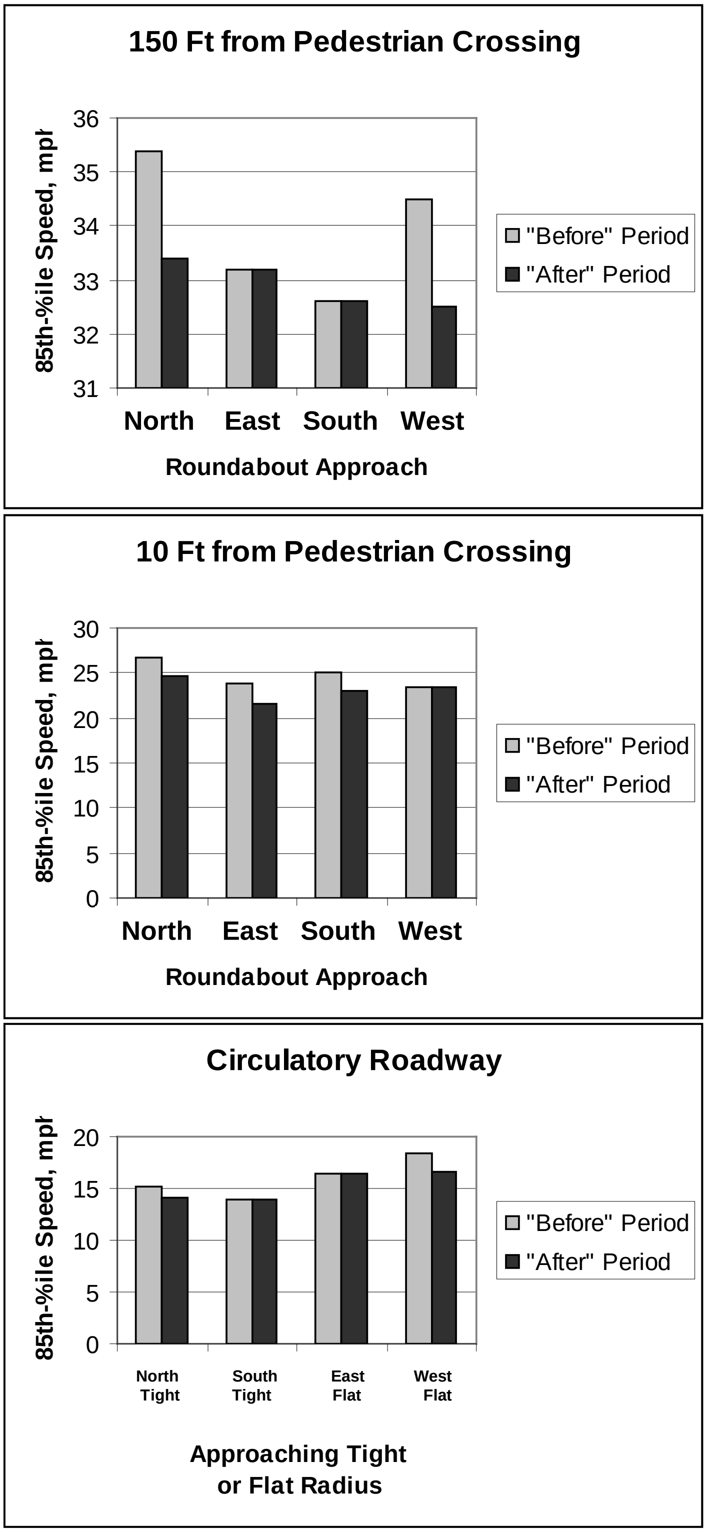


FIGURE 16 Graphical View of Difference in "Before" and "After" Period 85th-Percentile Speeds, mph

Locations with statistically similar mean speeds were grouped together according to their location category within the roundabout and their study periods. When compared, if the grouped speeds were not significantly different at the 95 percent confidence level, all speeds of the same category were combined. Grouped category speeds showed that points within the circulatory roadway were not significantly different in the before and after period, while grouped speeds 10 and 150 ft from the pedestrian crossing were found to be significantly lower in the "after" period than the "before" period.

Capacity Data Analysis Results: Critical Gap

The range of critical gap time was estimated by using only 95 percent of the total number of overlapping largest rejected and smallest accepted gaps to exclude outliers. Frequency distributions of the data collected for the "before" and "after" periods are shown in FIGURE 17.

The lower bound of the critical gap was 0.6 seconds less in the "after" period than in the "before" period.

- **Before Period:** 3.1 seconds < Critical Gap Range < 4.1 seconds
- **After Period:** 2.5 seconds < Critical Gap Range < 4.1 seconds

This change can be attributed to the overall decrease in speeds observed in the "after" period. Due to decreased speeds in the roundabout circulatory roadway, drivers accepted shorter gaps upon entrance, perhaps feeling more secure about merging their vehicles in the circulatory traffic stream since approaching drivers were traveling slower. Since the lower bound of the critical gap decreased, the potential capacity of the roundabout increased.

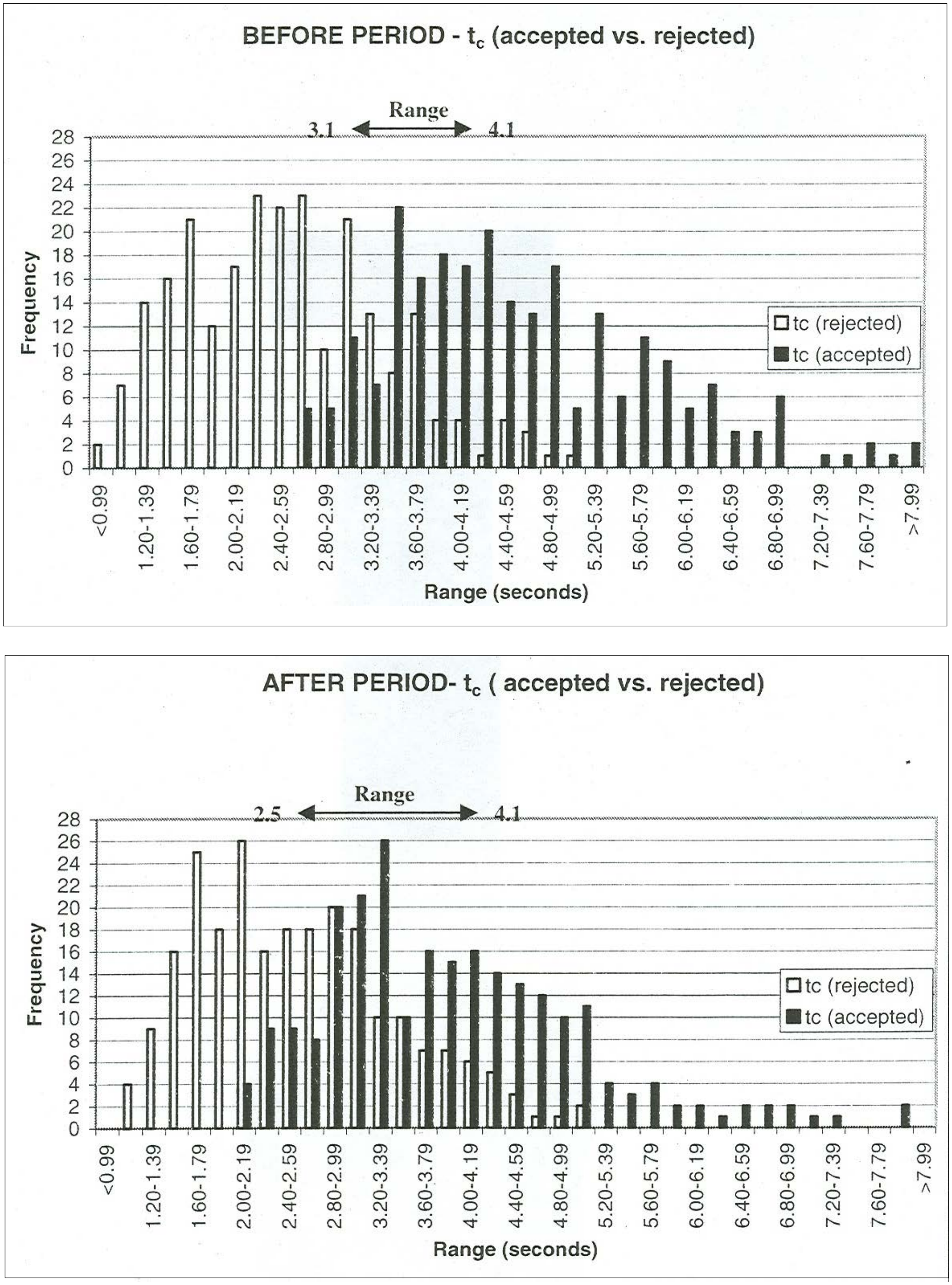


FIGURE 17 Frequency Distributions for Critical Gap, t_c, in the "Before" and "After" Periods

Capacity Analysis Results: Follow-up Time

Estimates of follow-up time were made from the north, south and west approaches. The east approach was blocked by trees on the videotape (refer to the camera view shown in FIGURE 10). The follow-up time was estimated to be the same for both periods, using the highest and lowest time observed in the videos as limits:

- **Before Period:** 1.1 seconds < Follow-up Time Range < 2.7 seconds
- **After Period:** 1.1 seconds < Follow-up Time Range < 2.7 seconds

Even though the range in the "after" period was slightly larger (0.9 seconds to 3.1 seconds), it was determined to use the same range as in the "before" period because there was only one observation less than 1.1 second and two observations greater than 2.7 seconds out of more than 100 observations. FIGURE 18 shows the frequency distributions for follow-up time, t_f, in the "before" and "after" periods.

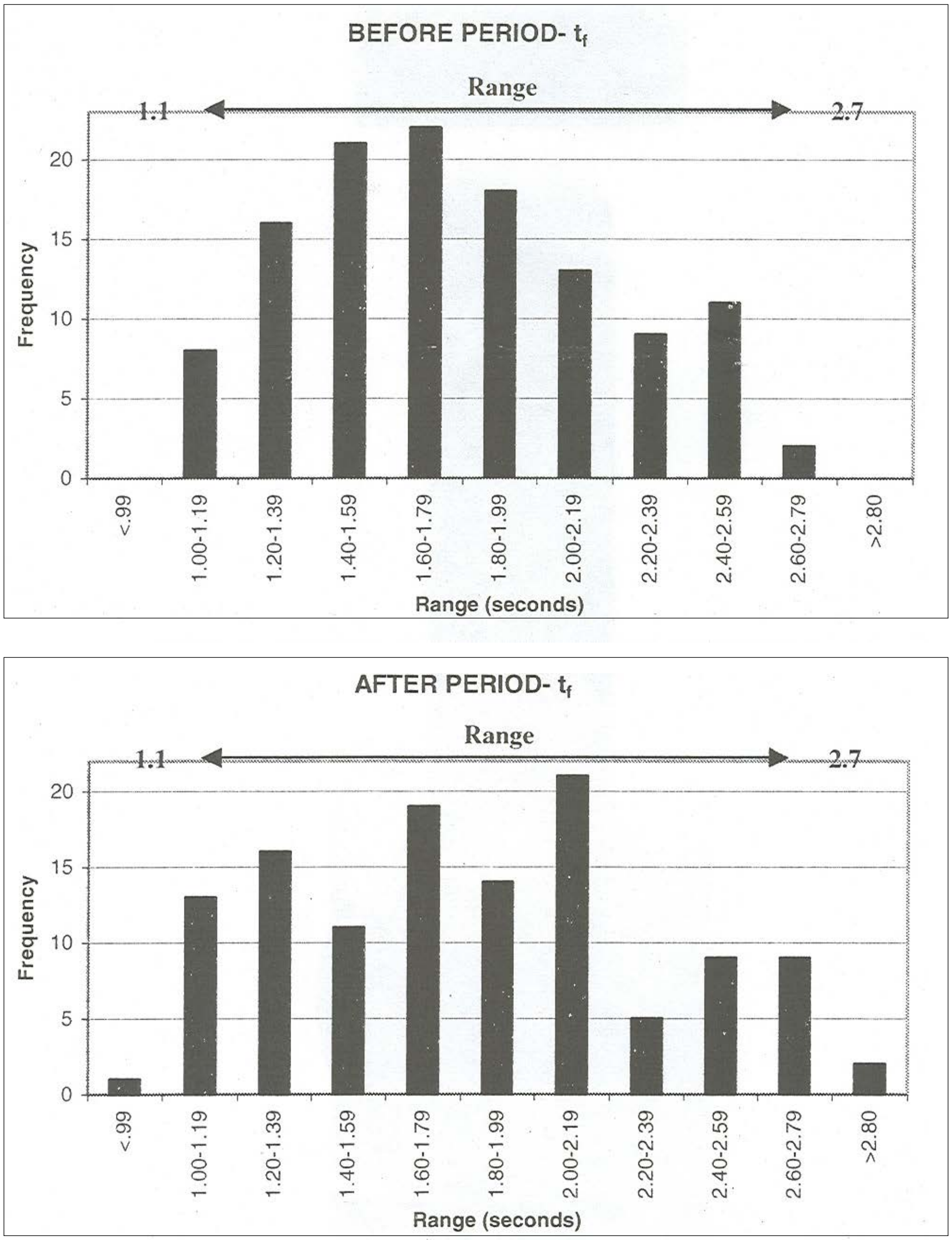


FIGURE 18 Frequency Distributions for Follow-Up Time, t_f, in the "Before" and "After" Periods

FIGURE 19 shows the potential approach capacity ranges of the study site roundabout given upper and lower boundary values of critical gap and follow-up time from the field study. The default values used in the HCM 2000 are shown for reference purposes. The lower boundary value from the field study closely parallels the upper boundary default value. The upper boundary field study value is much larger than the HCM 2000 method prediction but is limited by the 1,800 vph practical maximum dictated by the HCM 2000 method. Of course, such high capacity values would only result if optimal critical gap and follow-up times were practiced by every driver in the system.

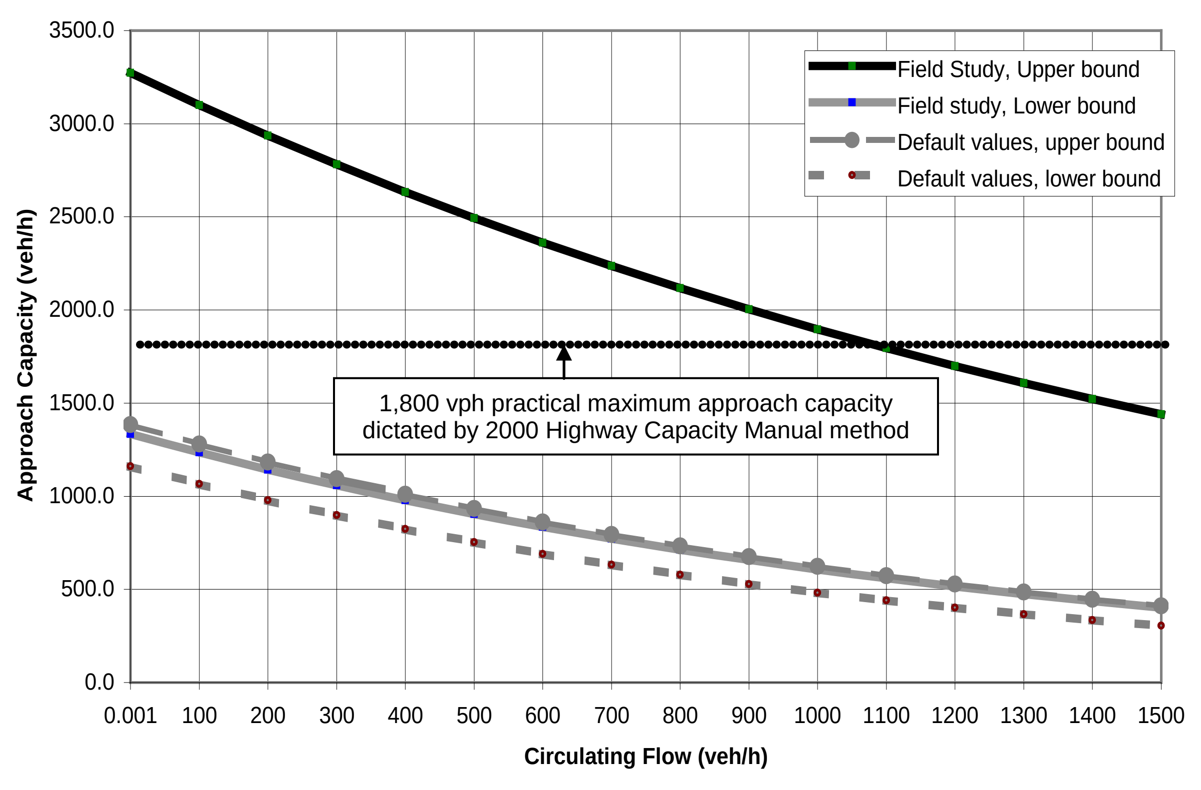


FIGURE 19 Graphical Representation of Capacity at Sheridan Blvd and 33rd Street Roundabout Using the 2000 Highway Capacity Manual Method
(Note: Default values from HCM 2000 shown for reference)

Pedestrian-Bicyclist Behavior Study Results

Pedestrian facilities at the study site such as sidewalks, curb ramps, and painted crosswalks were designed and built to applicable standards available at the time of design. FHWA documents used for guidance were, “Roundabouts: An Informational Guide” (*1*), and the most current editions of the “Manual of Uniform Traffic Control Devices” or MUTCD (*8*), and Americans with Disabilities Act Accessibility Guidelines (*9*) or ADAAG. The design of the sidewalk alignment was also influenced significantly by the available public right-of-way at the study site. FIGURE 20 shows the pedestrian crosswalk on the north approach of 33rd Street.

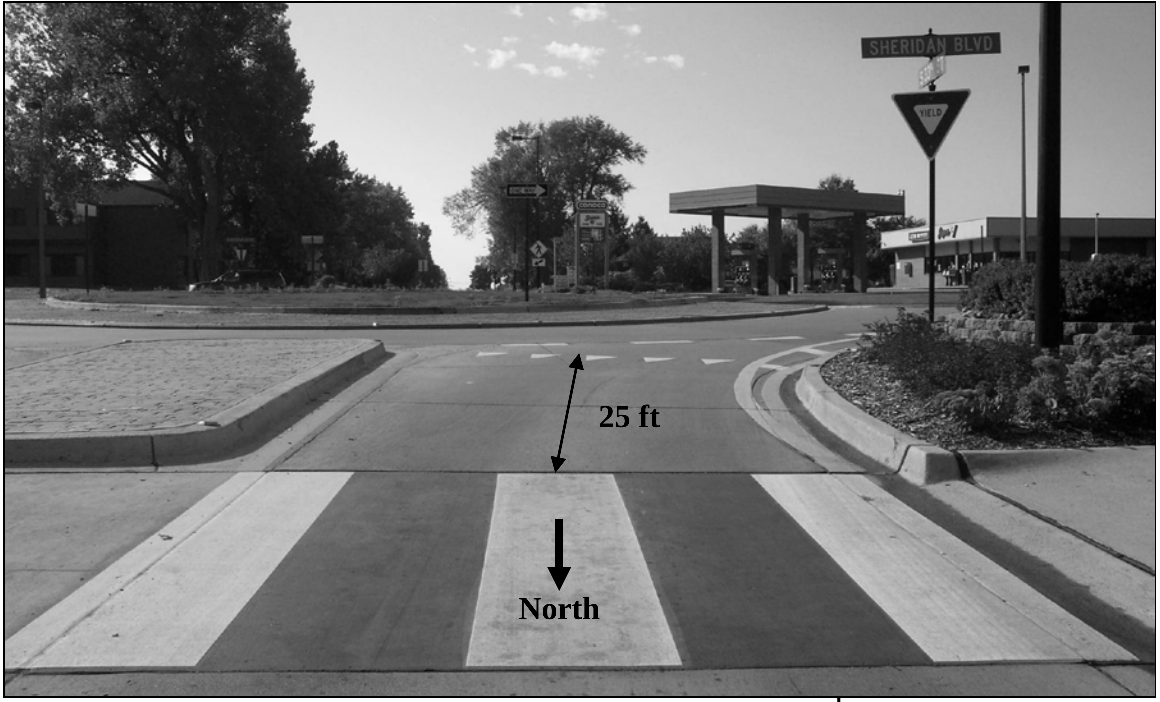


FIGURE 20 Pedestrian Crosswalk at Sheridan Blvd and 33rd Streets

All crossings were positioned 25 ft in advance of the sawtooth yield pavement markings on the approaches. Dark tinted concrete was used from roadway curb to splitter island curb for the width of the pedestrian “zebra” pavement striping to further delineate the crossing location from the rest of the roadway. Although data from other countries suggest that the presence of markings has no appreciable effect on pedestrian safety, they do provide guidance for pedestrians in navigating a roundabout and provide a visual cue to drivers of where pedestrians may be within the roadway (*1*). Splitter islands were interrupted to create pedestrian refuges to allow the possibility of crossing the two-way streets in two stages during high traffic conditions as shown in FIGURE 21. Wide boulevard splitter island refuge sidewalk alignments were designed with “S” curves to alert users that they must cross the exit lane of the roundabout before reaching the opposite side of the street.

FIGURE 21
Pedestrian/Bicyclist Refuge Within Splitter Islands

Videotapes of the study site were reviewed to document pedestrian behaviors within the boundaries of the roundabout. Of primary interest were actions of pedestrians and bicyclists and pedestrian-bicyclist-vehicle interactions that were directly a result of the geometry of the roundabout roadway.

TABLE 6 shows the sample sizes of pedestrians and bicyclists observed in the "before" and "after" conditions. All observations were made by the same graduate research assistant. There were a limited number of videotapes recorded in the "before" period. It was desired to obtain at least 200 observations of pedestrians and 50 bicyclist observations, so videotapes in the "after" period were reviewed until that number was reached or exceeded. The number of bicyclists may be slightly larger due to the "after" observations being taken during the warmer months of 2003.

TABLE 6. Number of Observations of Crossing Pedestrian and Bicyclists at Study Site

Study Period	Number of Pedestrians Observed	Number of Bicyclists Observed
Before	241	51
After	245	123

In about a third of the observations recorded, there were occurances when vehicles were in the proximity of pedestrians and bicyclists as they were stopped or hesitating before entering the crosswalk either at the curb ramp (vehicle approach) or splitter island (vehicle exit) location. TABLE 7 shows the percentage of those occurances in which vehicles yielded to pedestrians and bicyclists. The actual number of occurances is shown in parentheses after the percentage values.

TABLE 7. Percentage of Vehicles Yielding to Pedestrians Entering Crosswalk

Study Period	Pedestrians		Bicyclists	
	Yes	No	Yes	No
Before	41% (25)	59% (36)	65% (11)	35% (6)
After	58% (46)	42% (33)	70% (23)	30% (10)

The results show that although drivers should always yield to pedestrians in crosswalks by law, many of them don't. The "after" period resulted in a greater percentage of vehicles yielding to both pedestrians and bicyclists. This may have been due to the fact that vehicle speeds were lower and more uniform in the "after" period, making it more conducive for drivers to stop.

TABLE 8 shows the percentage of the total of pedestrians and bicyclists that came to a complete stop before crossing an approach or an exit. The actual number of observations is shown in parentheses after the percentage values.

TABLE 8. Percentage of Pedestrians and Bicyclists That Stopped Before Crossing an Approach or Exit Roadway

Study Period	Percentage of Pedestrians That Stopped Before Crossing		Percentage of Bicyclists That Stopped Before Crossing	
	Yes	No	Yes	No
Before	21% (48)	79% (186)	28% (13)	72% (47)
After	17% (41)	83% (195)	19% (19)	81% (82)

Slightly fewer pedestrians and bicyclists stopped in the "after" period. This may have been due to the increase number of drivers that yielded to them.

TABLE 9 depicts the average time pedestrians or cyclists waited before departing from a standstill at the crosswalk ramp or splitter location. The actual number of observations is shown in parentheses after the percentage values.

TABLE 9. Time Pedestrians and Bicyclists Spent Waiting to Enter Crosswalk

Study Period	Pedestrian Waiting Time, Seconds	Bicyclist Waiting Time, Seconds
Before	5.1 (24)	2.5 (6)
After	2.5 (20)	6.7 (13)

Pedestrians spent less time waiting to cross in the "after" period, which again may have been due to the increased percentage of drivers that yielded to them. However, bicyclists waited a longer time in the "after" period. Waiting time depended on traffic volume and driver behavior which could have varied widely causing the increase in bicyclist delay.

TABLE 10 shows the average time pedestrians and bicyclists hesitated before entering the crosswalk.

TABLE 10. Time Pedestrians and Bicyclists Hesitated Before Entering Crosswalk

Study Period	Pedestrian Hesitation Time, Seconds	Bicyclist Hesitation Time,Seconds
Before	0.9	0.7
After	0.5	0.7

Hesitation time remained about the same in both “before” and “after” periods.

TABLE 11 shows the percentage of the total sample size that chose the shortest path to cross.

TABLE 11. Percentage of Pedestrians and Bicyclists Choosing the Shortest Path of Crossing to Destination

Study Period	Pedestrians		Bicyclists	
	Yes	**No**	**Yes**	**No**
Before	8% (20)	92% (221)	10% (5)	90% (46)
After	8% (20)	92% (225)	6% (7)	94% (116)

“Short cut” behavior was nearly the same in both “before” and “after” periods. It appears that neither landscaping condition had a significant effect on pedestrian and bicyclist hesitation or choice of shortest path behaviors.

The most pedestrian activity at the study site occurred along the north and west approaches. An access point to a city park hiker-biker trail was located in the northwest quadrant adjacent to the roundabout and a convenience store with fuel pumps was located in the southwest quadrant of the intersection. FIGURE 22 shows a line drawing plan view of the study site with undesirable pedestrian behaviors marked with dashed arrows.

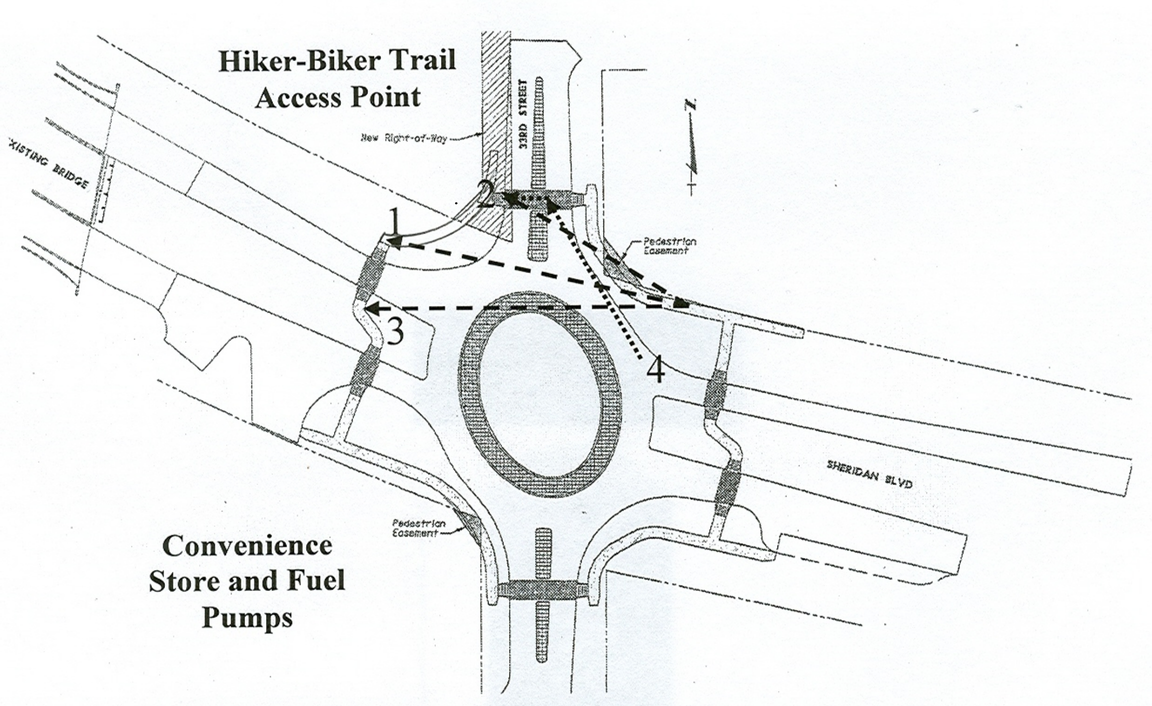


FIGURE 22 Undesirable Pedestrian Path Choices

By far, the undesirable behavior witnessed most on the videotapes reflected path choices by some pedestrians to take the shortest path across the intersection with little regard for surrounding traffic. Behavior 1 shown in FIGURE 22 was used by the same individual every morning. Behavior 2 was a “short cut” to and from the hiker-biker access point. The red-tinted brick-imprinted truck apron was also used as a “refuge” for individuals walking diagonally across the intersection (Behavior 3), again with minor attention to vehicles within the circulatory roadway. This “short cut” behavior may have been reduced if the pedestrian ramps had been connected with a shortest-path diagonal alignment but right-of-way restrictions did not allow shortest-path options.

Bicyclists observed traversed the roundabout as a roadway user (see FIGURE 1B) or used the sidewalk and crosswalk. A few westbound bicyclists were viewed using both the roadway and part of the crosswalk to enter the hiker-biker access point (Behavior 4 in FIGURE 22).

Chapter 6
CONCLUSIONS

Overall, drivers' choice of vehicle approach speed was found to be significantly lower in the "after" condition than the "before" condition at locations 10 ft and 150 ft in advance of the pedestrian crosswalk. Speeds within the circulatory roadway were generally found to not be significantly different at the 95 percent confidence level when data for all four locations were grouped for analysis of the entire category.

Drivers' choice of vehicle speed was also more uniform in the "after" period as evidenced by lower standard deviations. Both of these operational changes would inherently yield safer conditions for drivers, pedestrians and bicyclists. The severity of both vehicular crashes and pedestrian/bicyclists mishaps decreases drastically with changes in speed as shown in FIGURE 23 (*10*).

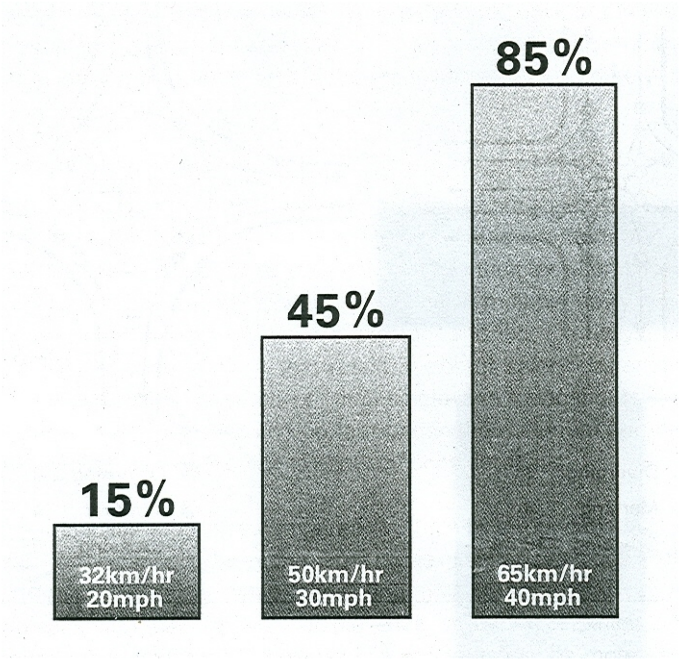


FIGURE 23 Pedestrian Chance of Fatality If Hit by Motor Vehicle

In NCHRP Report 500, Volume 10: A Guide for Reducing Collisions Involving Pedestrians, speed is sited as a major contributing factor in pedestrian crashes of all types (*11*). At higher speeds, motorists are less likely to see and react to a pedestrian or bicyclist, and are even less likely to be able to stop in time to avoid hitting one. Volume 10 also lists speed reduction of motor vehicles as one of four strategy emphasis areas for reducing pedestrian-vehicle conflicts and improving pedestrian safety and mobility (*11*) .

Another one of the four strategy emphasis areas cited in Volume 10 is improving sight distance and visibility for motor vehicles and pedestrians. This strategy somewhat restricts the findings of this research project. Although the addition of the 3 evergreen trees at the study site appears to have resulted in reducing driver vehicle speed choices, completely blocking the sight lines across the central island would be contrary to the safety strategy cited above. Therefore, planting and objects that occupy more vertical space than horizontal space with significant gaps between feature placements is recommended. This balance between sight blockage and open space may reduce driver speed choice while still providing suitable views across the central island.

Positive traffic operational conditions also resulted from the addition of the 3 evergreens in the "after" period. The lower boundary of the critical gap in the "after" condition decreased by 0.6 seconds, increasing the potential capacity of the roundabout as a system.

The overall conclusion of this study is driver, pedestrian, and bicyclist safety and traffic operations benefits can be realized from providing landscaping treatments in the central island of a roundabout. However, the central island landscaping elements must be placed with care recognizing the appropriate limits of stopping and intersection sight distance sight lines and roadside design guidelines, and must be of sufficient volume to be visible in advance of the pedestrian crossing, but also limited to minimizing the obstruction of cross view sight lines to optimize the view of pedestrians and bicyclists within the roadway portions of the roundabout. Funding for the determination of optimal sight blockage requirements was not available, but due to these conflicting effects, further study is recommended.

STUDY LIMITATIONS

This study had a limited budget and no control site to study in conjunction with the before-after changes made at the Sheridan Blvd and 33rd Street roundabout. A control site roundabout would have helped to ensure that landscaping changes were truly the cause of the change in speeds from "before" to "after" condition, rather than some other external source.

Another uncontrollable drawback was the collection of "before" data only three months after the newly constructed roundabout was open to traffic. This time constraint was due to the necessary placement of the central island spruce trees in autumn of 2002, the optimum seasonal time for successful transplanting of tree-type vegetation. This time period was viewed as adequate for the study since the intersecting routes were located within a long-established neighborhood serving primarily commuter traffic. It appears that the "before" condition time period did not affect the study adversely since speeds were slower and more uniform in the "after" period. Intuitively, one would expect slower speed choices by drivers to occur when less familiar with a driving environment.

Chapter 7

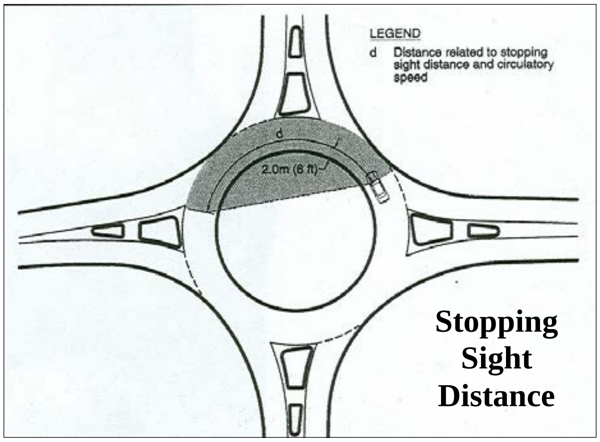
RECOMMENDATIONS

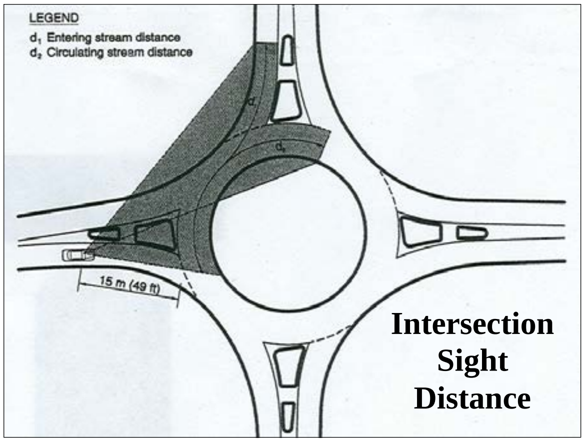
The following recommendations have been developed from the review of central-island landscaping research literature and the results of this study.

Recommendations for Central Island Landscaping at Single-Lane Roundabouts for Optimal Safety and Operations

RECOMMENDATION #1:

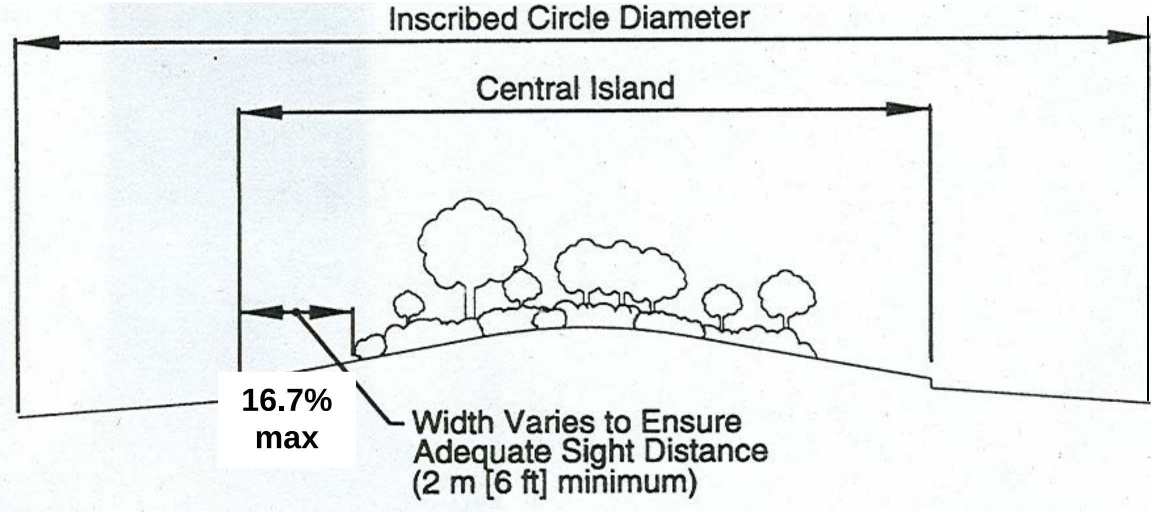
Follow current guidelines for stopping and intersection sight distance.





RECOMMENDATIONS #2:

Follow current guidelines for a forgiving roadside. Avoid the following items within the central island: trees with large diameter stumps, guardrail, concrete barriers, fences, walls, piers, sign or light poles, hard objects, statues, and fountains.



RECOMMENDATION #3:

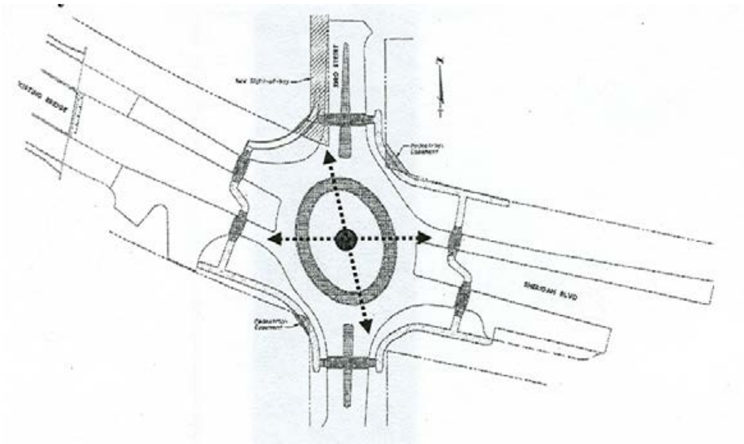
Use the central island as an aesthetic focal point by planting landscaping materials that require minimum maintenance and watering. All plantings will require some care and even some watering in unexpected drought conditions. The choice of plantings should be appealing but not so much that pedestrians cross to the center island to have their picture taken with a stunning backdrop. According to landscape architects, plants go in and out of favor over time and new diseases are a challenge to even the hardiest of species, so specific plant types will not be suggested.

RECOMMENDATION #4:

Use some coniferous plant material that is at least 6 ft high and at least 4 ft in diameter at initial planting time and up to 20 ft tall and 10 ft in diameter at maturity. Choose plantings with the smallest diameter mature stump size possible.

RECOMMENDATION #5:

Space high, slender plants strategically to maximize view between elements and minimize view of approach traffic on the opposite site of the roundabout. Be mindful of the initial AND mature size of planting to avoid future sight restrictions. Be mindful of the drifting effect large plantings may cause and plan ahead to minimize snow build-up in the circulatory roadway.

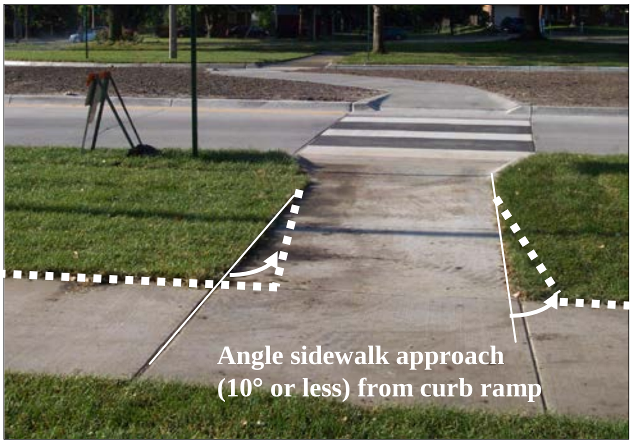


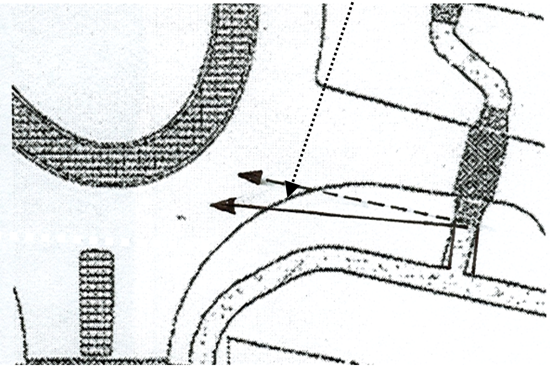
RECOMMENDATION #6:

Avoid deciduous plantings that may drop leaves within the circulatory roadway and make it slippery if wet.

RECOMMENDATION #7:

Slightly angle the sidewalk approach to the pedestrian curb ramp to favor the pedestrian's peripheral view (normally 180° from straight ahead) of exiting vehicles from the roundabout. NOTE: Pedestrian curb ramps must be as close perpendicular to the traffic flow as possible to avoid unintentionally guiding blind pedestrians toward the circulatory roadway.





Improved peripheral vision of approaching vehicles

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